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Essays in international trade and the environment: Applications of Heckscher-Ohlin and non- traditional trade theories

Antoinette Mary James
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**Essays in international trade and the environment: Applications
of Heckscher-Ohlin and non-traditional trade theories**

James, Antoinette Mary, Ph.D.

University of New Hampshire, 1993

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ESSAYS IN INTERNATIONAL TRADE AND THE ENVIRONMENT -
APPLICATIONS OF HECKSCHER-OHLIN AND
NON-TRADITIONAL TRADE THEORIES

BY

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DISSERTATION

Submitted to the University of New Hampshire
in Partial Fulfillment of
the Requirements for the Degree of

Doctor of Philosophy
in
Economics

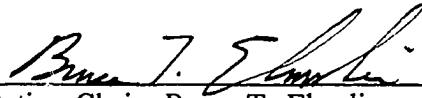
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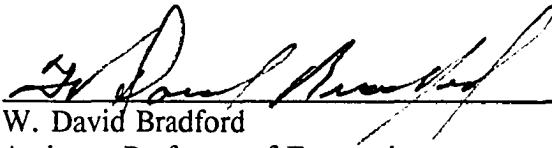
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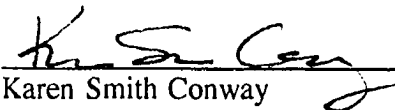
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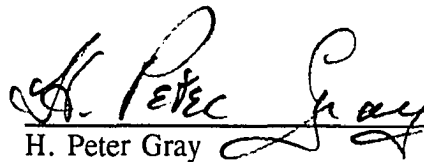
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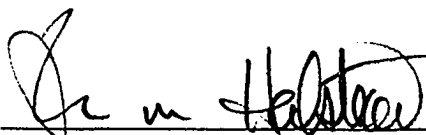
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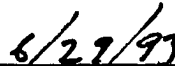
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This dissertation is dedicated to my parents, Claire and Richard James, for their support, encouragement, and patience. I hope I have made you proud.

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ABSTRACT

ESSAYS IN INTERNATIONAL TRADE AND THE ENVIRONMENT - APPLICATIONS OF HECKSCHER-OHLIN AND NON-TRADITIONAL TRADE THEORIES

by

Antoinette M. James
University of New Hampshire, September, 1993

The essays in this dissertation examine the implications of a country's use of the environment for its trade patterns. The first essay provides the foundation for the empirical analysis conducted in the second essay. The first essay examines empirical research in Heckscher-Ohlin trade theory with the intent of establishing the limits of the theory and some reasons for its lack of empirical support. The essay concludes that Heckscher-Ohlin is a specialized theory of trade flows between countries with similar endowments and which are at similar stages of development. The explanation for the poor empirical performance lies in applications of the model which have instead used groups of very diverse nations.

The second essay discusses an empirical application of the Heckscher-Ohlin-Vanek model to a group of similarly endowed and developed countries. The specification of the model also expands the list of traditional factors of production considered to include the environment. The empirical analysis shows that even in a setting that appears to better fit the assumptions of Heckscher-Ohlin theory, rather than exports being of products using a country's more abundant factors, the Leontief

paradox is confirmed in which exports are of products using a country's more scarce factors. The model does not support a significant role for the environment with respect to trade flows, but the environment variable is shown to influence the results obtained.

The third essay considers the literature on dynamic comparative advantage and develops a theoretical model that incorporates the impact of the environment over time. The model demonstrates that as increasing pollution destroys the productivity of labor, trade in a world of two countries declines with decreasing productivity advantages until it ceases altogether. As environmental quality is degraded, international economic activity grinds to a halt. This result is reached by considering the environment in a dynamic setting where the full implications of pollution can be expressed. The contribution of this dissertation is the description of a research agenda for the analysis of the impact of the environment on trade flows in a dynamic setting.

INTRODUCTION

The motivation for this dissertation is an interest in the general issue of the relationship between international trade and the environment. In particular, the focus here is on the implications of a country's use of its environment for its trade patterns. There has been a great deal of interest in this area lately, as Reinstein (1991: 1) states:

[t]rade was in many ways the dominant issue of the 1980s, and environment is emerging as the issue of the 1990s. The two issues are closely related and many believe that environment will, in fact, be the number one trade issue of the 1990s.

In light of this interest and the importance of addressing the degradation of the global environment, this dissertation presents a timely discussion of one aspect of the economy-environment connection. The expectation is that the issues raised here will become part of the discussions of national and international economic and environmental policies.

The dissertation is comprised of three essays (sections). The first essay provides the foundation for the empirical analysis conducted in the second essay. The first essay examines empirical research in Heckscher-Ohlin trade theory (Heckscher 1919, Ohlin 1933) with the intent of establishing the limits of the theory and some reasons for its lack of empirical support.

The first essay begins with a description of the Heckscher-Ohlin theory and the multicountry, multifactor, multicommodity Heckscher-Ohlin-Vanek model (Vanek 1968). In the latter form, the Heckscher-Ohlin-Vanek theorem states that a country

will export the services of its relatively abundant factors and import the services of its relatively scarce factors. In empirical analysis, it is important that separate measures of the three key variables are used, namely, net exports of commodities, factor intensities, and factor endowments.

The essay continues with a discussion of the empirical results obtained from factor content studies of the Heckscher-Ohlin-Vanek model. The results, in general, do not support the Heckscher-Ohlin theory, but rather confirm the paradox found by Leontief (1953) that the reverse is true - exported products use the relatively scarce factors intensively. These results motivate the search for either a method of estimating the model such that the prediction of the theory is supported, or an explanation for the persistence of the paradox (which represents a refutation of the theory).

The essay then discusses the data requirements for the three main variables. The construction of the matrix of factor intensities is the most complex, and the discussion includes the Hamilton and Svensson (1983) proof of the necessity of Input-Output Tables in constructing this matrix. The requirements for the matrices of factor endowments and net trade are also examined.

The essay next analyzes the importance of the assumptions of a theoretical model to conducting empirical work in the context of the Heckscher-Ohlin-Vanek model. The particular concern is with the requirements necessary to achieve the assumption of factor price equalization in Vanek's expanded model. The literature notes a key requirement - that countries must be similar in relative factor endowments

- which should be considered when conducting empirical analyses. The impact of this requirement is to limit the applicability and usefulness of Heckscher-Ohlin theory; this limitation is explored in the second essay.

The first essay concludes that Heckscher-Ohlin is a specialized theory of trade flows between countries with similar endowments and which are at similar stages of development. The explanation for the poor empirical performance lies in applications of the model that have instead used groups of very diverse nations.

In response to this finding, the second essay presents an empirical application of the Heckscher-Ohlin-Vanek model to a group of similarly endowed and developed countries. The specification of the model addresses the primary issue of the dissertation by expanding the list of traditional factors of production considered to include the environment.

The second essay begins with a discussion of the environment as a factor of production, and the concept of environmental assimilative capacity. To introduce the main issue of the dissertation, the literature on environment and trade from both economic and legal perspectives is examined.

The essay continues with the structure of the empirical model and the method of introducing the environment into the model. This work follows McGuire (1982) in conceiving of the environment, for use in a Heckscher-Ohlin model, as the output of pollutant emissions. Baumol and Oates (1971) are the source of the interpretation of emissions outputs as equivalent to inputs; this interpretation makes McGuire's approach appropriate. In the model in this dissertation, the environmental factor is

measured as the output of air pollutant emissions. The state of environmental regulations in the countries used in this study is also discussed. The countries used - Canada, France, West Germany, Italy, Japan, the United Kingdom, and the United States - seem to be a group that are similar in relative factor endowments for the time period of the study. The empirical analysis is introduced by examining the empirical studies of Leonard (1988) and Tobey (1990), neither of which found the environment to have an influence on trade flows.

The second essay then presents the empirical model beginning with an overview of the data and the statistical techniques employed. The results of both the nonparametric statistics and regressions are next analyzed. The analysis shows that even in a setting that appears to better fit the assumptions of the Heckscher-Ohlin-Vanek model, rather than exports being of the services of a country's more abundant factors, the Leontief paradox is confirmed in which exports are of the services of a country's more scarce factors. In addition, the model does not support a significant role for the environment with respect to trade flows. In an appendix analyzing the data set without the environment variable, the results suggest that the environment variable has a large influence on the results obtained in the second essay.

The third essay begins with the premise that the failure to find a strong role for the environment in a Heckscher-Ohlin model results because the important dimension of environmental degradation as a dynamic problem cannot be captured in a static framework. Thus, this essay considers the literature on dynamic comparative

advantage and develops a theoretical model that incorporates the impact of the environment over time.

The essay begins with a distinction between static and dynamic concepts of pollution. The static concept notes that at any point in time, emissions will be generated in the production process, while the dynamic concept recognizes that in addition, pollutants tend to accumulate in the environment over time. The essay also distinguishes between the static and dynamic versions of comparative advantage. Static comparative advantage (such as that present in Heckscher-Ohlin theory) is associated with the factors of production or technology with which a nation is endowed. Dynamic comparative advantage involves the idea that over time the industries in which a country has a comparative advantage will change as the relative endowments or technologies in which the country has a comparative advantage change.

The essay then lays the foundation for the theoretical model to be developed by discussing a model which uses a dynamic concept of pollution, Asako (1979), and a model of dynamic comparative advantage, Krugman (1987). The essay next presents the theoretical model which follows Krugman in its basic structure, but introduces a dynamic concept of pollution into the framework. The model demonstrates that as increasing pollution destroys the productivity of labor, trade in a world of two countries declines with decreasing comparative productivity advantages until it ceases altogether. As environmental quality is degraded, international economic activity

grinds to a halt. This result is reached by considering the environment in a dynamic setting where the full implications of pollution can be expressed.

This dissertation contributes to the literature on empirical applications of the Heckscher-Ohlin-Vanek model by considering both the factors included in the model and the requirement of factor endowment similarity. This dissertation also contributes to the literature investigating the relationship between international trade and the environment by conducting an empirical analysis using the Heckscher-Ohlin-Vanek model and by constructing a theoretical model of dynamic comparative advantage with a dynamic concept of pollution. The resulting contributions draw the future of the Heckscher-Ohlin theory into question and provide an argument for considering the impact of the environment in a dynamic setting.

SECTION 1

A SURVEY OF EMPIRICAL TESTING

OF THE HECKSCHER-OHLIN TRADE THEORY

The purpose of the first essay is three-fold. First, this essay will provide a thorough examination of empirical research in Heckscher-Ohlin trade theory, primarily the factor content studies, including an explanation of the various forms in which the empirical tests have been developed, the manner in which published data are transformed for use in testing, and the results obtained. This discussion is necessary because of the difficulties in understanding the tests and interpreting the results, which stem from the problems involved in developing empirical models that are compatible with the theoretical model.

Second, this essay will define the limits of Heckscher-Ohlin theory, in terms of the type of trade it is able to explain. Namely, Heckscher-Ohlin is a long-run theory designed to explain net trade flows in different products (interindustry trade), that arise from differences among countries in their relative endowments of factors of production. It is the dominant theory for describing the sources of, and gains from, interindustry trade. Empirical investigations of Heckscher-Ohlin should be targeting settings that meet the requirements of the model, and should seek to develop as full an understanding as possible of interindustry trade, recognizing that this type of trade constitutes only part of all world trade flows. In other words, this essay will clarify what our expectations should be for the Heckscher-Ohlin model's ability to describe real world trade.

Finally, this essay has as its ultimate purpose to analyze the Heckscher-Ohlin research agenda and outline the paths it has taken to this point and should take in the future. This entails a close examination of the assumptions of the model, especially

the requirement that countries be similar in relative factor endowments, which is necessary in order for factor price equalization - an important assumption of the expanded multicountry version of the model - to be achieved. In addition, motivation for examining the research agenda comes from the fact that many newer models that seek to explain other types of trade, like Helpman (1981) or Grossman and Helpman (1991), build upon Heckscher-Ohlin as an explanation for interindustry trade and net intraindustry trade (trade in differentiated products). Given the continued interest in the theoretical literature, it is important to determine whether empirical applications of this model support the theory, or suggest that another approach should be taken.

I. BACKGROUND

The Heckscher-Ohlin theory of international trade (Heckscher (1919), Ohlin (1933)) and the extension by Vanek (1968) to multiple factors of production, commodities, and countries represent a method of explaining trade flows based on comparative advantage deriving from differences in relative factor endowments in a static setting of perfectly competitive markets and constant returns to scale. While its elegance and theoretical consistency have given dominance to this theory, empirical applications of Heckscher-Ohlin theory have produced poor results.

Empirical testing began with Leontief (1953), followed by (among others) Leamer (1980), Brecher and Choudhri (1982), Leamer (1984), Maskus (1985), Bowen, Leamer, and Sveikauskas (1987), and Brecher and Choudhri (1988). These tests have varied in their degrees of support for the theory, the forms in which the equations have been specified (especially with regard to the variable s_k (see below)), and the data sets used.

Given the influence these papers and the Heckscher-Ohlin model have had, it is important that the empirical literature be examined in some detail. In addition, the general failure of the tests motivates a search for ways to improve empirical results either by a different specification for the variables in the model or a re-examination of the testing methodologies. Leamer (1992) looks at empirical research in international trade and concludes that its purpose should be to determine in which settings the

different models are most appropriate. As I will argue, the failures in Heckscher-Ohlin-Vanek research may be due in part to the use of inappropriate settings.

It should be emphasized that this examination of Heckscher-Ohlin theory is not designed to claim a larger role for the theory in discussions of international trade. The subject matter in the international field is too diverse for any one theory to lay claim to the entire domain.¹ This analysis seeks to determine if Heckscher-Ohlin is adequate to describe its portion of international trading behavior.

The primary goal of this essay is to provide a concise discussion of empirical research in Heckscher-Ohlin theory for international trade economists. One contribution of this essay is as a counterpart to Maskus (1991). Whereas Maskus set out to detail data sources and their coordination for use with Heckscher-Ohlin models, I intend to provide details on transforming the available data to fit the variables used in the empirical model and analyzing the results. This represents a significant contribution to a literature which has heretofore relegated such explanations (if they appear at all) to extremely obscure data appendices. This essay is also to be distinguished from Leamer (1992) which provides a broad discussion of other types of trade theories - such as Ricardian, increasing returns, growth, and imperfect competition - in addition to Heckscher-Ohlin. Leamer's (1992: 4) basic argument concerning empirical research in international trade is that, "[w]e need some sensible

¹ Although Ohlin might have held a different opinion in 1933, in the revised version Ohlin (1967) notes that he has changed his mind. There were a number of issues that could not be handled by building on the factor proportions theory as a base, so the international field necessarily requires "sub-" or partial theories dealing with different topics.

balance between these three layers - issues, theory and data." This essay examines the status of the balance of theory and data in Heckscher-Ohlin research.

The need for explanations and clarifications of past empirical research stems from the difficulty in understanding, and interpreting the results of, the tests that have been done. It is difficult to determine how available data has been adapted to the model, and how the tests relate to the model. A sufficient amount of empirical research has been done to merit this type of critical review.

In addition, such a review will be of benefit to future empirical work on the Heckscher-Ohlin model. Future research is warranted, given that current theoretical work, such as Helpman (1981) and Grossman and Helpman (1989, 1991), begins with Heckscher-Ohlin as an explanation of interindustry (and net intraindustry) trade, and extends it by incorporating increasing returns or dynamics to explain other features such as intraindustry trade (trade in differentiated products) or technological progress. With Heckscher-Ohlin such a fundamental part of international trade theory, it is important to continue examining its contribution to our understanding of the world trading system.

II. THE HECKSCHER-OHLIN-VANEK MODEL

The Heckscher-Ohlin theory in its simplest form posits a world of two countries that each differ in the amounts of two factors of production they are endowed with: one has relatively more labor than capital, the other relatively more capital than labor. These factors are used to produce two goods, one which requires relatively more labor to be produced, the other requires relatively more capital. The Heckscher-Ohlin theorem states that trade will take place between these two countries, each of which was originally producing both goods in autarky (that is, before trade), because of the global cost savings of specialization. The country with relatively more labor will produce the good that requires more labor in production, the other country will specialize in the good that requires more capital.

The natural comparative advantage of having relatively more of a factor of production makes producing certain goods cheaper; the benefit to trade is obtaining other goods from countries that can produce them more cheaply. This is the essence of the factor endowments-based, comparative advantage model laid out by Heckscher (1919) and Ohlin (1933). The $2 \times 2 \times 2$ model rests on assumptions of balanced trade, no monetary distortions, and full employment. Samuelson (1949) is the source of the assumptions for the mathematical specification of the $2 \times 2 \times 2$ model.

Vanek (1968) expanded the Samuelson version of this basic model to consider more than two countries, more than two factors, and more than two goods. In this

expanded form, the Heckscher-Ohlin-Vanek theorem states that a country will export the services of its relatively abundant factors and import the services of its relatively scarce factors. Empirical estimation of the model typically involves a multi-dimensional form such as Vanek.

In both forms, Heckscher-Ohlin is a theory of trade in different products - interindustry trade - and allows no justification for trade in differentiated products - intraindustry trade. Other theories have been developed specifically to explain the generation of trade in differentiated products, as in recent years intraindustry trade has been the dominant type of trade conducted, especially between industrialized countries.²

The Heckscher-Ohlin-Vanek theorem is based on the following assumptions:

(a) there are m factors of production which are perfectly immobile between countries; (b) there are n (greater than or equal to m) commodities which are freely mobile between countries; (c) all consumers have identical homothetic preferences; (d) all countries have identical constant returns to scale production functions; (e) factor and commodity markets are perfectly competitive with no distortions; and, (f) factor prices are equalized across countries.³ Important requirements for the last assumption to be met are that countries are not too dissimilar in relative factor

² Interestingly, one feature that Ohlin (1933) discussed as generating trade flows is the presence of increasing returns in certain industries. This feature has come to be one of the primary features of theories of intraindustry trade.

³ Vanek arrives at this last assumption by following the Heckscher-Ohlin-Samuelson assumptions. Bertrand (1972) specifically challenges both the factor price equalization and identical demand conditions assumptions in his reformulation of Vanek (1968), and develops a model that requires neither assumption.

endowments (see especially Heckscher (1919) and Samuelson (1949)), and there are no factor intensity reversals (Johnson (1957)). These requirements will be discussed further below.

From these assumptions, the Heckscher-Ohlin-Vanek model consists of relationships between factor endowments, factor intensities, and net trade across countries and industries. Specifically, the Heckscher-Ohlin-Vanek equations take the form:

$$[1] \quad AT_k = V_k - s_k V_w \quad \text{for each country } k$$

- where:
- (1) A is an $m \times n$ matrix of factor intensities; an element a_{ij} is the input of factor i required per unit of output of commodity j
 - (2) T_k is an $n \times 1$ vector of net exports of commodities
 - (3) V_k is an $m \times 1$ vector of factor endowments ($W = \text{world}$)
 - (4) s_k is country k 's consumption share of world output; this is also expressed as GNP in country k (Y_k) less its trade balance (B_k) divided by world GNP: $s_k = C_k/C_w = (Y_k - B_k)/Y_w$.

One important (and extremely controversial empirically) result of the assumptions of the Heckscher-Ohlin-Vanek model is that the A matrix will be the same for all countries. This follows from the fact that technologies, which vary by industry, are assumed to be the same in each country, and that factor prices will be equalized across countries. These assumptions that result in the single A matrix are rather strong assumptions to make (even compared to the stringency of the other assumptions of the model) and contribute to the problems experienced by this model in empirical tests.

A complete empirical test of the Heckscher-Ohlin-Vanek equations requires separate measurements of the three elements: net exports of commodities (T), factor intensities (A), and factor endowments (V).⁴ Such a test has rarely been attempted in the empirical work to date; however, Maskus (1985) is considered the first such test and another example of this approach is Bowen, Leamer, and Sveikauskas (1987). The latter is the approach to be used in the second essay.

A typical single-factor equation, which is a row from equation [1], will take the form:

$$[2] \quad F_{xk}^i = F_k^i - (C_k/C_w)F_w^i \quad \text{for each country } k$$

- where:
- (1) F_{xk}^i is the total (direct plus indirect) quantity of any factor i embodied in a country's net exports (x), that is, F_{xk}^i is an element of AT_k
 - (2) F_k^i, F_w^i are the endowments of factor i in country k and the world
 - (3) C_k, C_w are the consumption expenditure levels in country k and the world, that is, a particular specification of s_k has been chosen.

Equation [2] is interpreted as stating that the factor content of net exports will equal the excess supply of the factor in country k . If a country is abundant in a factor relative to the rest of the world, the amount of that factor embodied in its exports will exceed that embodied in its imports. Abundance of a factor is indicated by a

⁴ Deardorff (1984), Leamer (1984), Maskus (1985), and Bowen, Leamer, and Sveikauskas (1987) all refer to such an empirical test as logically complete because it involves independent measures of the three elements. Other tests, such as Leamer (1984), either do not involve all three elements, or infer one from the other two.

country's endowment exceeding its consumption expenditure share of the world's endowment.

Equation [2] is the basic equation from which the nonparametric tests are derived, and upon which the regression analysis is based. Information about the statistics associated with the empirical application of the model is presented in the second essay. The primary difference among the existing empirical tests of the Heckscher-Ohlin-Vanek model is the particular test (or tests) performed; that is, regression analysis versus some or all of the nonparametric tests. There is reason to question the implications of regression analysis for this model, given the restrictiveness of its assumptions relative to the real world trading picture. As will be discussed below, the failure of the Heckscher-Ohlin-Vanek model to perform well in an empirical setting is likely the result of the model's having far too restrictive assumptions to adequately explain real world trade flows. Maskus (1985: 209-211) argues that the restrictive assumptions of the Heckscher-Ohlin-Vanek model are a reasonable explanation for its empirical failure, and suggests that further research be conducted on other versions of a factor endowments trade theory. It is precisely because of the assumptions that the empirical testing needs to be re-examined; the problems of the assumptions point to a limited domain for the theory.

III. SURVEY OF EMPIRICAL HECKSCHER-OHLIN-VANEK RESULTS

Empirical testing⁵ of Heckscher-Ohlin began with Leontief (1953). The paradoxical results he obtained spawned a profusion of attempts to contradict, explain, or otherwise provide more consistent results, primarily in the context of the expanded Heckscher-Ohlin-Vanek model. From the voluminous literature on empirical testing a number of articles have been chosen for detailed examination here that have had an important impact on the literature.

There are generally recognized to be four major lines in empirical testing in the Heckscher-Ohlin-Vanek tradition.⁶ Three of these methodologies are not considered to be complete tests in the sense that they include measurements of only two of the three elements of the Heckscher-Ohlin-Vanek equations, trade (**T**), factor intensities (**A**), and factor endowments (**V**), and infer the value of the third. Factor content studies such as Leontief (1953) and cross-commodity regression studies such as Baldwin (1971) use measures of **T** and **A** and infer or simply assert the value of **V**. Cross-country regression studies such as Leamer (1984) use measures of **T** and **V** to implicitly infer **A**. Criticisms have been raised regarding the validity of these inferences. While these studies may be testing the influence of factor intensities

⁵ One should be cautious about the meaning of the word "testing" in this context. Heckscher-Ohlin-Vanek is not tested against any alternative hypothesis, but rather evaluated as to its accuracy in explaining trade flows when confronted with actual trade data. Leamer (1992) prefers estimation as a more appropriate term.

⁶ Maskus (1991) and Leamer (1992) provide more detailed discussions of the distinctions between the various types of testing that are summarized here.

or factor endowments on trade flows, they are not specifically testing the relationship between the three variables present in the Heckscher-Ohlin-Vanek equations. The fourth major line is that represented by Bowen, Leamer, and Sveikauskas (1987) which actually uses measurements of all three elements. The articles that are discussed here fall into one or another of these four major lines of empirical research.

The research in the Heckscher-Ohlin-Vanek tradition is to be distinguished from other works such as Deardorff (1982) and Balassa and Bauwens (1988) which have extended Heckscher-Ohlin to the multicommodity, multifactor context in a manner quite different from that used by Vanek (1968). These works have been subject to different criticisms and are not discussed further here because they are so methodologically distinct from the Heckscher-Ohlin-Vanek analysis.

Let us begin with Leontief (1953) which is characterized as a factor content study because Leontief examined the total (direct plus indirect) capital and labor requirements per million dollars of exports and competitive imports.⁷ These requirements were used to determine whether the United States (in 1947), which was asserted to be a relatively capital-abundant country, was an exporter of capital and an importer of labor. The attainment of such a result would support Heckscher-Ohlin. Leontief's results are presented below in Table 1 (adapted from Leontief 1953 (1968): 522).

⁷ This is not total imports, but imports of products that directly compete with U.S. products.

Table 1
Domestic Capital and Labor Requirements per Million Dollars
of U.S. Exports and Competitive Import Replacements
(Average 1947 Composition)

	Exports	Import Replacements
Capital (in 1947 prices)	\$2,550,780	\$3,091,339
Labor (man-years)	182.313	170.004

Leontief provides no measures of factor endowments,⁸ and derives the paradoxical results that although apparently a capital-abundant country, U.S. exports required relatively less capital and relatively more labor than its competitive imports. Interestingly, Leontief's response to his results is not to discredit Heckscher-Ohlin as an explanation of trade flows, but to try to make an interpretation of his results that removes the paradox. His interpretation is based on the relative productivity of U.S. versus foreign labor. He assumes that U.S. labor is more productive than foreign, so that one U.S. worker is equal to three foreign. This is used to calculate "equivalent" workers in the United States - a number three times as large as the actual number of workers. On this basis, capital is scarce relative to labor in the United States, so the results presented in Table 1 are consistent with Heckscher-Ohlin.

Leamer's (1980) refutation of the paradox present in Leontief's results appeared after Vanek (1968) extended the basic 2x2x2 Heckscher-Ohlin model to the multicountry, multicommodity, multifactor setting. Leamer shows that Leontief's finding that the United States was relatively better endowed with labor relative to capital, because the capital requirement per million dollars of exports was less than

⁸ Although for this time period, the assumption of relative capital abundance is probably secure, especially compared to the major trading partners of the United States.

the capital requirement per million dollars of competitive imports, is valid only if the sign on net exports of capital services is opposite to the sign on net exports of labor services.

Factor services are calculated by multiplying factor requirements by the amount of exports or the amount of imports. In 1947, U.S. exports were \$16,678.4 million and U.S. competitive imports were \$6,175.7 million (Leamer 1980: 503).

Multiplying these by the corresponding figures in Table 1 (above) yields the net export figures shown in Table 2 (below) - the United States is a net exporter of both capital and labor services.

If, as in 1947 by Leontief's own data, the country is a net exporter of both capital (K) and labor (L), the factor content of net exports should be compared to the factor content of consumption (defined as production less net exports). That is, since for the United States the following conditions held:

$$K_{Ek} - K_{Mk} > 0 \quad \text{and} \quad L_{Ek} - L_{Mk} > 0$$

where K_{Ek} , L_{Ek} are the factor content of exports of country k and K_{Mk} , L_{Mk} are the factor content of imports, capital would be revealed to be abundant relative to labor if

$$\frac{(K_{Ek} - K_{Mk})}{(L_{Ek} - L_{Mk})} > \frac{K_{Ck}}{L_{Ck}}$$

where K_{Ck} , L_{Ck} are the factor content of consumption. This follows from Leamer's Corollary 1 which is based on Vanek's (1968) model (equations [1] and [2] above).

Leamer combines production data with Leontief's trade data and presents the results shown below in Table 2 (adapted from Leamer 1980: 503).

Table 2
Capital Intensity of Consumption and Trade

	Net Exports	Consumption
Capital (millions)	\$23,450	\$305,069
Labor (million man-years)	1.99	45.28
Capital/labor (per man-year)	\$11,783	\$6,737

Using the appropriate comparison, between factor contents of net exports and consumption rather than between factor requirements of exports and imports, the paradox is removed - the United States is revealed to be relatively abundant in capital. The capital/labor ratio for net exports is \$11,783 per man-year which is greater than the capital/labor ratio for consumption of \$6,737 per man-year.

Leamer (1980) is devoted mostly to the derivations of corollaries that indicate the comparisons that are valid in various circumstances. One important result to come out of these corollaries is the focus on net exports. As Leamer demonstrated, distinguishing exports and imports is not always equivalent to looking at net exports. Another important result is that Leontief's procedure is really only valid in the Heckscher-Ohlin world of two commodities.

Brecher and Choudhri (1982) suggest that Leamer (1980) was successful as far as his analysis went, but an examination of the implications of Leamer's Corollary 1 points out a lingering paradox in Leontief's results. By manipulating equation [2] (from above), Brecher and Choudhri show that a country can only be a net exporter of labor services if its aggregate expenditure per worker is less than that in the rest of the world. Replacing F^i in equation [2] with L , we have:

$$L_{xk} = L_k - (C_k/C_w)L_w$$

where L_{xk} is the amount of labor embodied in net exports, L_k and L_w are the labor endowments of country k and the world, and C_k , C_w are the aggregate expenditure levels (consumption) in country k and the world, or by rearranging:

$$L_{xk} = L_k \left[1 - \left(\frac{C_k}{C_w} \right) \left(\frac{L_w}{L_k} \right) \right]$$

which implies that:

$$L_{xk} > 0 \text{ if and only if } C_w/L_w > C_k/L_k.$$

Recall that $C_k = Y_k - B_k$, that is, consumption is the difference between GNP and the trade balance (net exports). Then lower per capita consumption corresponds to higher per capita net exports. A country will be a net exporter of labor services if it spends more per capita on net exports than it does on domestic consumption. Per capita consumption in country k will be less than the world average because for country k to be a net exporter of labor services it must require less per capita domestically to generate a surplus of labor services for export.

However, by examining Leontief's (and other) data, Brecher and Choudhri report that U.S. expenditures per worker in 1947 were greater than that in many other countries.⁹ Thus, they find remnants of the paradox persisting.

The formal proofs developed in Leamer (1980) and the further proof offered in Brecher and Choudhri (1982) form the foundation for the empirical tests developed in Maskus (1985), which are by now standard fare in empirical factor content studies of

⁹ They do not provide the data upon which they base their calculations, but they report that for various European countries the range of expenditures per worker was 45 to 61 percent of the U.S. level.

Heckscher-Ohlin-Vanek. Maskus (1985) is a response to two weaknesses Maskus saw in empirical research on Heckscher-Ohlin-Vanek. The first was the lack of any attempt to measure factor endowments; instead researchers had been relying on inference from measures of trade flows and factor intensities. The second weakness was the lack of logically consistent empirical tests of Heckscher-Ohlin-Vanek to examine the relationships between the three elements. Maskus provides measures of factor endowments, as well as factor intensities and trade flows, and develops three tests for use in empirical Heckscher-Ohlin-Vanek research.

All three tests are based on the following equation,¹⁰ first presented in Leamer (1980) based on Vanek (1968):

$$[3] \quad F_{Ek}^i - F_{Mk}^i = F_k^i - (C_k/C_w)F_w^i$$

where F_{Ek}^i and F_{Mk}^i are the total (direct plus indirect) amounts of the factor i embodied in country k 's exports and imports, F_k^i and F_w^i are the endowments of the factor in country k and the world, and C_k and C_w are aggregate consumption in country k and the world, so C_k/C_w is country k 's share in world consumption. Equation [3] shows that in order for a country to be a net exporter of a factor, its endowment of that factor must exceed its consumption share of the world's endowment of the factor.

The first test, referred to in Maskus (1985) as the "weak" test, is based on the observation by Brecher and Choudhri (1982) that equation [3] implies that

$$F_{Ek}^i - F_{Mk}^i > 0 \text{ if and only if } C_k/F_k^i < C_w/F_w^i;$$

¹⁰ This equation is essentially the same as equation [2].

that is, a country will be a net exporter of a factor if and only if its aggregate expenditure per unit of that factor is less than world expenditure per unit of the factor. The "weak" test examines whether these inequalities hold for a given data set.

The second test is the "rank" test which is based on the relationship between factors derived from equation [3]. For two factors, capital (**K**) and labor (**L**), that are both net exports from country **k**, if the following inequality holds, capital would be revealed to be abundant relative to labor:

$$\frac{(K_{Ek} - K_{Mk})}{K_k} > \frac{(L_{Ek} - L_{Mk})}{L_k}.$$

Inequalities of this type (shares of factors exported) can be established for a list of factors and used to create a ranking of the relative abundance of factors in a country revealed through trade flows. The "rank" test compares this ranking to one based on independent measures of factor endowments, expressed as shares of the world's endowment. That is, relative capital abundance in country **k** would be revealed by:

$$K_k/K_w > L_k/L_w.$$

The final test is the "strong" test which requires that the following equality hold (equation [3] is rewritten):

$$\frac{C_w}{F_w^i} = \left(\frac{C_k}{F_k^i} \right) \left[\frac{1}{1 - \frac{(F_{Ek}^i - F_{Mk}^i)}{F_k^i}} \right].$$

If a country's trade in a factor is balanced, expenditure per unit of that factor must be the same in that country and the world. If the country has positive (negative) net exports of that factor, the world's expenditure per unit will be larger (smaller).

If expenditure per unit of a factor is the same in country k and the world, the distribution of that factor must be adequate as is, and country k 's trade in that factor will be balanced. If expenditure per unit of a factor differs between country k and the world, either country k or the world has a greater need for the factor, and exports of the factor's services will be biased towards whichever has the greater need.

Table 3 summarizes the three tests.

Table 3
Test Methodologies

Test	Expected Results
"weak"	$F_{xk}^i > 0 \Leftrightarrow C_w/F_w^i > C_k/F_k^i$ (both positive) $F_{xk}^i < 0 \Leftrightarrow C_w/F_w^i < C_k/F_k^i$ (both negative) $F_{xk}^i = 0 \Leftrightarrow C_w/F_w^i = C_k/F_k^i$ (both equal)
"rank"	$F_{xk}^i/F_k^i > F_{xk}^j/F_k^j \Leftrightarrow F_k^i/F_w^i > F_k^j/F_w^j$ $F_{xk}^i/F_k^i < F_{xk}^j/F_k^j \Leftrightarrow F_k^i/F_w^i < F_k^j/F_w^j$
	this can be extended to a list of factors rather than using pairwise comparisons
"strong"	$C_w/F_w^i = C_k/F_k^i[1/(1 - F_{xk}^i/F_k^i)]$ must hold so either: $C_w/F_w^i = C_k/F_k^i \Leftrightarrow F_{xk}^i/F_k^i = 0$ $C_w/F_w^i > C_k/F_k^i \Leftrightarrow F_{xk}^i/F_k^i > 0$ $C_w/F_w^i < C_k/F_k^i \Leftrightarrow F_{xk}^i/F_k^i < 0$

note that this is just a strengthening of the requirements of the "weak" test.

Maskus conducted these tests on data for 1958 and 1972 for a "world" consisting of the United States and 33 (or 5, on a smaller test of similar countries) trading partners for three factors - skilled labor, unskilled labor, and gross physical

capital. Some of Maskus' results are presented in Table 4 on the following page (adapted from Maskus 1985: 208).

The "weak" test results involve columns (a), (c), (d), and (e). In column (a), the United States is shown to be a net exporter of all factors in 1958 and a net importer of all factors in 1972. Thus, the expected results of the "weak" test (column (d)) are that $C_w/F_w^i > C_{us}/F_{us}^i$ in 1958 and $C_w/F_w^i < C_{us}/F_{us}^i$ in 1972. Looking at columns (c) and (e), we see that these results hold for capital in 1958 and for all factors in 1972.

The "rank" test results involve columns (a), (b), (f), and (g). The values in column (a) give the ranks in column (b), and the values in column (f) give the ranks in column (g). The rankings in column (b) are expected to match those in column (g) - note that the only matches are for skilled labor in 1958 and for unskilled labor in 1972.

The "strong" test results involve columns (e) and (h). Column (e) is the observed value of C_w/F_w^i , while column (h) is the value of C_w/F_w^i calculated from $C_k/F_k^i[1/(1 - F_{xk}^i/F_k^i)]$. These two values are expected to be equal for each factor, however, they are substantially different except for capital in both years.

Thus, Maskus' results are mixed at best, although he finds some support for the "weak" test, and his conclusion is that Leontief's paradox appears to persist.¹¹

¹¹ In a footnote, Maskus states that a referee suggested that the "strong" test may be unreasonable given the problems of international data comparisons, and recommended more reliance on the two weaker tests. For somewhat different reasons, I argue below for less emphasis on the "strong" test or regression analysis.

Table 4
Tests of the HOV Theorem in Three Factors Using
a 34-country World, 1958 and 1972

Factor	(a) $(F_E^i - F_M^i)/F_{US}^i$	(b) Rank	(c) C_{US}/F_{US}^a	(d) Weak Prediction	(e) C_W/F_W^b	(f) F_{US}/F_W	(g) Rank	(h) Strong Prediction C_W/F_W
1958								
Skilled labor	0.0165	2	\$60,157	<	\$37,697	0.3189	2	\$61,166
Unskilled labor	0.0181	1	\$ 7,287	<	\$ 1,752	0.1223	3	\$ 7,421
Capital	0.0133	3	0.6003	<	0.6237*	0.4222*	1	0.6084
1972								
Skilled labor	-0.0011	1	\$95,616	>	\$64,322	0.2693	2	\$95,511
Unskilled labor	-0.0075	3	\$16,229	>	\$ 4,857	0.1198	3	\$16,108
Capital	-0.0072	2	0.7270	>	0.6283	0.3460	1	0.7218

^a U.S. aggregate expenditure per unit of factor endowment.

^b World (U.S. plus 33 countries) aggregate expenditure per unit of factor endowment.

*Note - Maskus' World values for capital in 1958 are based on 1963 data.

In response to his results, Maskus states that he would still suggest an important role for relative factor endowments in determining world trade flows, however "the most reasonable interpretation is that the HOV assumptions are simply too restrictive for that version of the factor endowments theory to hold in an empirical context."

(Maskus 1985: 209-211)

Bowen, Leamer and Sveikauskas (1987) was published later than Maskus' article, but apparently was written concurrently. Interestingly, the testing done in their article roughly parallels Maskus' tests. They specify the equation used by Maskus in matrix form (the same as equation [1]), and examine the extent to which the equality in that equation is violated by conducting sign and rank tests on a data set for 1967 consisting of a "world" of 27 countries and twelve factors - net capital stock, total labor, seven separate categories of workers, and three types of land. In addition, they perform regression analyses that allow different assumptions of the Heckscher-Ohlin-Vanek model to be relaxed to examine alternative hypotheses to Heckscher-Ohlin-Vanek. Here, only their sign and rank tests will be further discussed.¹²

The sign test involves computing the percentage of matches between the sign on net exports of a factor (F_{xk}^i) and the sign on a country's excess supply of that factor ($F_k^i - (C_k/C_w)F_w^i$). It is similar to Maskus' "weak" test in terms of the relationship it attempts to capture. It should be noted that Bowen, Leamer, and

¹² As discussed in more detail below, I have reservations about the usefulness of regression analysis in the Heckscher-Ohlin-Vanek context. As noted by Bowen, Leamer, and Sveikauskas (1987: 792, 793), the Heckscher-Ohlin-Vanek equations are not just equalities, but identities. This seems to lead to difficulties in interpreting deviations from the restricted model.

Sveikauskas adjust their measures of the factor content of trade and relative factor endowments by the country's income share of the world (Y_k/Y_w) and also adjust for the country's trade imbalance. As they and Kohler (1991) point out, there have been a variety of similar adjustments made by other researchers, and some (like Maskus) make no adjustments at all. The result is a slight difference in the interpretation of factor abundance used in the various studies.¹³

The rank test is essentially the same as Maskus' in that it examines the extent to which the two rankings of factor abundance conform - the ranking by net factor exports (F^i_{xk}/F^i_k) and the ranking by factor endowments (F^i_k/F^i_w). Bowen, Leamer, and Sveikauskas examine rankings across factors for a single country, as well as across countries for a single factor.¹⁴ Heckscher-Ohlin-Vanek implies that both types of ranking should be consistent. Tables 5 and 6 below present some of their results (adapted from Bowen, Leamer, and Sveikauskas 1987: 796-797).

Table 5
Sign and Rank Tests, Factor by Factor

Factor	Sign Test ^a	Rank Test ^b
Capital	.52	.45
Labor	.67	.46
Arable Land	.70	.73

^a Proportion of 27 countries for which the sign of net trade in factor matched the sign of the corresponding factor abundance.

^b Proportion of correct rankings out of 351 possible pairwise comparisons.

¹³ Kohler (1991) examines the extent to which the different versions yield different results empirically, and finds a lack of robustness to the different specifications. He argues that a researcher should examine all specifications.

¹⁴ They only examine factors or countries in pairs, rather than evaluating the entire list at once.

Table 6
Sign and Rank Tests, Country by Country

Country	Sign Test ^a	Rank Test ^b
Canada	.75	.64
France	.25	.71
Germany	.67	.76
Italy	.58	.69
Japan	.67	.71
United Kingdom	.92	.78
United States	.58	.67

^a Proportion of 12 factors for which the sign of net trade in factor matched the sign of the corresponding excess supply of factor.

^b Proportion of correct rankings out of 55 possible pairwise comparisons.

In general, for all countries and factors, Bowen, Leamer, and Sveikauskas find little support for the sign test, which deals with the abundance of a resource compared with a weighted average of other resources (i.e., the income share). Also, when examined across all factors and countries, they find little support for the rank test. They explain their extension to regression analysis in the following way:

Overall, the results for the sign and rank propositions offer little support for the H-O-V model. However, the tests of these propositions do not refer to specific alternative hypotheses and may cast doubt on the H-O-V hypothesis for a variety of reasons, including nonproportional consumption, various kinds of measurement error, and differences in factor input matrices. These alternatives can be studied by regressions of factor contents on endowments... (Bowen, Leamer, and Sveikauskas 1987: 798)

Note that the regression analysis may be thought of as an examination of a more "general" explanation of trade, since it analyzes the contributions of elements of

Heckscher-Ohlin-Vanek and other trade theories.¹⁵ This may be an appropriate use of regression analysis in the Heckscher-Ohlin-Vanek context.

The approach found in both Maskus (1985) and Bowen, Leamer, and Sveikauskas (1987) is the approach chosen for use in the second essay in this dissertation. These papers represent the most complete response to Leontief (1953) and the attempts to re-examine his paradox by including measures of the three critical elements of Heckscher-Ohlin-Vanek: factor endowments, factor intensities, and trade.

A few other empirical papers in Heckscher-Ohlin-Vanek theory have also had some influence on the present research. One is Leamer (1984) which is noteworthy for its comprehensive treatment of empirical research in Heckscher-Ohlin-Vanek, from the theoretical foundations to data collection. As noted above, it is not a complete test of Heckscher-Ohlin-Vanek because it uses measures of trade (T) and factor endowments (V) only, while implicitly inferring factor intensities (A). Leamer himself acknowledges that such a study cannot be said to be measuring the accuracy of Heckscher-Ohlin-Vanek. However, in justifying the use of this approach, he argues:

In place of the hypothesis that A, T, and V fit together as predicted by the HOV equation, we substitute the hypothesis that T is a linear function of V. Interpreted as sharp hypotheses, these statements are virtually identical. The even [$m = n$] HOV model implies linearity, and conversely, linearity almost surely implies the even HOV model. However, interpreted as approximations, these two hypotheses may be quite different. It is conceivable that trade is "approximately" a linear function of endowments, but at the same time the HOV

¹⁵ For example, differences in factor input matrices (i.e., A is not the same for all countries) reflect the assumption of (neutral) technological differences, primarily between developing and developed countries.

equations do not hold, even "approximately". I shall ignore this possibility, since it depends on fuzzy notions concerning the adequacy of an approximation, and I shall proceed as if the demonstration of the accuracy of the estimated linear trade model were necessarily a demonstration of the accuracy of the HOV model. (Leamer 1984: 59)

The point to be made most strongly about Heckscher-Ohlin-Vanek is that when confronted with real-world trade data it cannot be thought of as more than a first approximation. For this reason alone, although there are others, we should be careful to include all three elements (A, T, and V) in empirical studies.

In addition, although they use a somewhat different approach, Brecher and Choudhri (1988) provide one of the arguments for limiting the size of the "world" - the number of countries included - in empirical Heckscher-Ohlin-Vanek research. As they note,

[i]n view of the evidence, one interesting possibility is that only a subset of countries satisfies the model's strong assumptions of internationally identical technology, tastes, and factor prices. (Brecher and Choudhri 1988: 5)

Their study uses only two countries - the United States and Canada. They develop the two-country Heckscher-Ohlin-Vanek hypothesis which states that the amount of a factor embodied in a dollar of domestic expenditure must be the same for both countries; that is,

$$F^i_{ck}/C_k = F^i_{c'k'}/C_{k'} \quad \text{for all } i$$

where F^i_{ck} is the amount of factor i embodied in the aggregate consumption bundle of country k .

They use a regression analysis and account for measurement errors and other problems, and find little support for Heckscher-Ohlin-Vanek in this two country

setting. However, since they have conducted none of the nonparametric tests, it is difficult to state conclusively that the idea of using a smaller subset of countries has not made much difference in improving overall empirical results in Heckscher-Ohlin-Vanek research.

This survey of research is representative of the results that have been obtained. Although not all the forms in which Heckscher-Ohlin-Vanek has been studied were discussed here, those results also show little support for Heckscher-Ohlin-Vanek. Thus, like many avenues of empirical investigation, this history leaves two options open: one is to conclude that further study would be futile, the second (more likely) option is to try to determine why success has been difficult to achieve. Such an attempt is being made here.

IV. APPLICATION OF THE DATA TO THE MODEL

The purpose of this section is to describe the development of a data set for empirical Heckscher-Ohlin-Vanek research. This involves finding and converting into useful form data for the three primary elements of equation [1] - trade (T), factor endowments (V), and factor intensities (A). I begin with the most problematic of the three elements.

A. The A Matrix

Inevitably, when one attempts to empirically estimate a theoretical model there will be problems in matching available data to the variables specified in the model.¹⁶ Sometimes the solution is the use of a proxy variable, but at other times the solution is more difficult because an adequate measure of the variable is not available. The latter is the situation that has existed with regard to the A matrix of equation [1].

The empirical papers discussed above refer to the fact that the A matrix is derived from the United States' (or some other country's) Input-Output Tables; however, none of these specifies precisely how this derivation is to be done. The problem is that the A matrix represents factors used to produce commodities, while the Input-Output Tables represent industry outputs used to produce commodities; the link between industry outputs and factors is not addressed in the empirical papers. It

¹⁶ As Gray (1989: 274) has discussed, "[f]or social scientists, the problem of measurement ... is more acute than for natural scientists...First, social scientists are likely to have to make do with data sources which collect data for different purposes than the hypothesis to be tested...Second, there is the problem of simple errors of measurement."

is addressed, however, in the theoretical paper by Hamilton and Svensson (1983) (only Maskus (1985) cites this source). Hamilton and Svensson also address the fact that in a complete test of Heckscher-Ohlin-Vanek it is total (direct plus indirect) factor intensities that are to be used, which is why it is necessary to use Input-Output Tables.¹⁷

Their proof for the use of total factor intensities proceeds as follows for the general $n \times n$ case of an equal number of traded goods and factors,¹⁸ incomplete specialization, factor price equalization, and all goods being traded. Throughout, factor intensities are defined as factor/output ratios.

There are two countries, Home and Foreign (the latter indicated by *). There are n traded goods, produced under constant returns to scale with n factors and intermediate inputs of n goods. There are also identical homothetic preferences and technology. All of these are consistent with the basic Heckscher-Ohlin-Samuelson assumptions.

Preferences can be represented by the expenditure function $E(p)u$ (because they are assumed to be homothetic), where p is the nominal goods price vector and u is the welfare level. The technology has two features:¹⁹ the constant ($n \times n$) goods input/output matrix B , which is independent of goods and factor prices; and, the

¹⁷ This same point was made by Leontief (1953); part of the purpose of that article was to introduce the (then new) technique of the Input-Output Tables.

¹⁸ The results also hold, though less clearly because of the tendency towards (complete) specialization, for the case of more goods than factors.

¹⁹ I have changed the notation used by Hamilton and Svensson in order to be consistent with the notation used by Vanek (1968) as well as in the other parts of the dissertation.

$(n \times n)$ matrix of direct factor/output coefficients $b(w)$, which is a function of w - nominal factor prices, meaning that $b(w)$ is variable and allows for substitution between factors. The remainder of the required variables are all n -vectors: factor endowment (V), gross output (Q), net output (X), consumption (C), and net trade (T).

For a given goods price vector p , an equilibrium with positive gross output for all goods and full employment of all factors can be represented as:

Home:	(a) $E(p)u = pX$	budget constraint
	(b) $X = Q - BQ$	net output definition
	(c) $p = pB + wb(w)$	zero economic profit condition
	(d) $b(w)Q = V$	factor market equilibrium
	(e) $C = E_p(p)u$	consumption bundle
	(f) $T = X - C$	trade vector definition

This system can be solved for the endogenous variables: u , X , Q , w , C , T . The equations for Foreign are similar; equation (c) is the same for both countries:

Foreign:	(g) $E(p)u^* = pX^*$	(h) $X^* = Q^* - BQ^*$
	(i) $b(w)Q^* = V^*$	(j) $C^* = E_p(p)u^*$
	(k) $T^* = X^* - C^*$	

The world equilibrium, with incomplete specialization and factor price equalization includes: (l) $T + T^* = 0$ world goods market equilibrium.

In order to derive the proof that trade depends on direct and indirect factor intensities, Hamilton and Svensson (1983: 456) first derive the result that the allocation of gross production depends only on direct factor intensities as follows. World equilibrium gross output is given by:

$$(m) \quad b(w)Q = V \qquad (n) \quad b(w)Q^* = V^*$$

since $b(w)$ is the same for both from the identical technology assumption. Assuming that $b(w)$ can be inverted, we get:

$$(o) \quad Q = b(w)^{-1}V \quad (p) \quad Q^* = b(w)^{-1}V^*$$

which yields the aforementioned result:

$$Q - Q^* = b(w)^{-1}(V - V^*),$$

Q is a function only of $b(w)$; B does not enter this equation. Thus, output decisions are made solely on the basis of factor market conditions, without concern for the demand for the output produced.

From this we can derive the result in which we are primarily interested, that "the trade vector depends on differences in the factor endowments and the *total* factor/output coefficients." (Hamilton and Svensson 1983: 457, emphasis in original) The derivation proceeds as follows.

Assume for simplicity that the countries are the same size, in that their national products are equal: $pX = pX^*$. Then, by equations (a), (e), (g), and (j), their consumption bundles are equal: $C = C^*$. Using this and (f), (k) and (l), we get:

$$C = C^* = (X + X^*)/2, \text{ from which (with (f)): } T = (X - X^*)/2 \text{ follows.}$$

Rewriting (b) yields: $X = (I - B)Q$ and $Q = (I - B)^{-1}X$. Substituting the latter into (d) yields: $b(w)(I - B)^{-1}X \equiv AX = V$, where $A = b(w)(I - B)^{-1}$ is total (direct plus indirect) factor/output coefficients. So similarly for Foreign we have: $AX^* = V^*$.

Assuming that A can be inverted we get: $X = A^{-1}V$, $X^* = A^{-1}V^*$ and substituting into the expression for T we get the result noted above: $T = [A^{-1}(V - V^*)]/2$, here T is a function of both $b(w)$ and B (in the form of A).

These results lead Hamilton and Svensson (1983: 457) to conclude that "in an analysis of the trade flows of commodities one should use total factor intensities." It is their definition of A above which provides the key to using the Input-Output Tables. They demonstrate that these tables are a necessary component of all complete tests of the Heckscher-Ohlin-Vanek model. This is so because in order to analyze trade flows we must bring in the demand for the final outputs. Thus, not only do we need to consider the relationship between factors and outputs, but also the relationship among outputs in the ultimate spending patterns of consumers (which will be identical because of homothetic preferences).

Therefore, the link between the industry outputs in the Input-Output Tables and the factors in the A matrix is addressed in the following way. The final version of the Input-Output Tables showing the matrix of total requirements of all commodities, direct and indirect, per dollar of delivery to final demand for all commodities (the Leontief inverse matrix $(I - B)^{-1}$) is pre-multiplied by a matrix $b(w)$ of direct factor/output ratios (the amount of each particular factor required per unit of output) for each industry in order to obtain the A matrix that appears in equation [1].

One must begin with the Input-Output Tables in order to construct the A matrix, and because of the aggregation across industries that is usually necessary,²⁰ the construction of the A matrix must precede all other data collection. As noted previously, the Heckscher-Ohlin-Vanek assumptions require that only one A matrix be

²⁰ Such aggregation is required in the attempt to achieve consistency in industry definitions. Aggregation creates problems for estimation in addition to those previously mentioned with respect to the A matrix.

used. In most cases, in which the United States is included in the "world", the U.S. Input-Output Tables are used since they are very detailed and readily available.²¹ The most structurally complete versions are available for Census years (years ending in 2 or 7), but do not appear in the *Survey of Current Business* until about seven years later.

If aggregation across industries is necessary, the published Leontief inverse version of the Tables cannot be used. Aggregation is usually performed to facilitate concordance across the different sources of trade, output, and endowment data. In the second essay, the industries used are limited to those in the manufacturing sector of the economy because data are more readily available for these industries, and because Maskus (1991) provides concordance tables for the ISIC and SITC codes²² for these industries, greatly facilitating the appropriate aggregation of the Input-Output Tables.

Aggregation of industries is performed on the "Use of Commodities by Industry" version of the Tables, and when completed, this version is manipulated to form the appropriate $(I - B)^{-1}$ matrix. The "Use of Commodities by Industry" table indicates the dollar amounts of the commodities (rows) from each sector of the economy used to produce final output in each industry (column) in the economy. Data are aggregated over both commodities and industries. Once aggregated, each

²¹ This does not mean, however, that the U.S. or any other Input-Output Tables are to be used without caution. Questions exist about the methodology of data collection and the assumptions underlying the construction of these tables.

²² ISIC - International Standard Industrial Classification; SITC - Standard International Trade Classification.

commodity input figure is divided by the total output of the appropriate industry in order to form the **B** matrix. The **B** matrix is then subtracted from an identity matrix of the same dimensions, and the result is inverted to form $(\mathbf{I} - \mathbf{B})^{-1}$.

The next step in constructing the **A** matrix is developing the matrix of factor-output ratios ($\mathbf{b(w)}$) for each industry and factor included in the study. These must be produced for the same year as the Input-Output Tables. These factor-output ratios are only collected for one country, the same as used for the Input-Output Tables. The factor-output ratios are the direct requirements of each factor to produce the final output of each industry. This $\mathbf{b(w)}$ matrix is multiplied by $(\mathbf{I} - \mathbf{B})^{-1}$ to produce the **A** matrix, the total (direct plus indirect) requirements of all factors to produce the final output of all industries. The dimensions of the resulting **A** matrix are the number of factors (rows) by the number of industries (columns).

B. The V and T Matrices

The development of the matrices of factor endowments (**V**) and net trade (**T**) is conceptually easier than the construction of the **A** matrix, but each of these matrices presents unique problems because data on many countries are necessary for both. In addition, the development of the capital endowment variable presents a challenge and there is the problem of the compatibility of industry definitions across countries.

Factor endowments are the amount of each factor available in each country included in the "world". These must also be obtained for the same year for which the **A** matrix is produced. It is here that the most problems arise in data availability,

resulting in considerable extrapolation for some countries, especially when developing labor endowments. Also, one must be careful that factor definitions are compatible among countries.

The capital endowment variable presents unique problems because information on capital stocks is difficult to obtain. Therefore, we find in practice that capital, a stock concept, is constructed based on flows of investment. This requires that investment flows be deflated and depreciated - presenting the question of the method of depreciation to use. Also, currencies must be converted into a single base (when using the United States for the A matrix the base is U.S. dollars), raising a question as to whether market exchange rates or purchasing power parity rates should be used. The empirical papers are not explicit on this point, but seem to use double-declining balance depreciation and market exchange rates; the latter are used because most trade data are converted using market rates. In the second essay both the straight-line and double-declining balance methods of depreciation are used, and conversions using both market exchange and purchasing power parity rates are made, to determine whether there is any reason to choose one method over another.

The following brief description of how the capital endowment variable is constructed presents a typical methodology. Investment flows are measured as "gross fixed capital formation," data on which are available from the International Monetary Fund (for instance, International Monetary Fund (1979)). Following Maskus (1991), a fifteen-year series is collected for each country and deflated using an investment price level index obtained from Summers and Heston (1988) (converted to the base

year of interest using U.S. investment deflators such as those available from the *Economic Report of the President* (1991)). Depreciation of the series is accomplished in one of two ways, in both cases an asset life of fifteen years is assumed: double-declining balance or straight-line. The former method assumes that asset values drop rapidly in early years and then less rapidly, while the latter assumes a constant rate of decline in asset values. The resulting series (in either case) is summed over the asset life for each country, and then converted into U.S. dollars (the base currency) using either market exchange rates (available from International Monetary Fund (1979)) or purchasing power parity rates (obtained from Ward (1985)). The former rate is based on prices of all goods, while the latter is based on the prices of a particular bundle of goods. Thus in the second essay, there are four capital variables which are considered separately.

The creation of the trade data base also follows a typical procedure. Trade data are collected from a source such as the United Nations (in this case United Nations (1978, 1979)) for all the countries included in the "world". Data are collected for the same industries as in the **A** matrix, and only for the particular trading partners in the "world". That is, rather than using total imports or total exports of an industry for a country, one uses only imports from or exports to the other countries included in the study. Net exports are calculated from separate import and export data, and aggregated over trading partners. The concordance for SITC industries from Maskus (1991) is used, but the ability to match industry codes does not remove all the uncertainty when working with data from many countries. Data should be relatively

compatible when collected from a single source, but industry definitions may still vary from country to country. In the second essay, the year chosen for study is 1977, a year when the trade classification systems for the countries included in the study were not all the same, meaning that definitional differences are possible. Attempts have been made since the mid-1980s to introduce more harmonization of industry definitions in trade data by various governments. In the meantime, one must assume that any differences in industry definitions have negligible effects on trade data compatibility.

There are other minor types of data problems. One is the restriction of the industries included to the manufacturing sector of the economy. This omits other goods-producing sectors of the economy, as well as the services sector. Another arises in the approach followed in order to construct the land-output ratios. In this approach, outputs of industries in the agricultural sector taken from the Input-Output Tables in dollar values must be converted into physical units that can be used in empirical estimation. Land-output ratios are developed as proportions of the appropriate agricultural industry from the Input-Output Tables (following Bowen, Leamer, and Sveikauskas (1987)). Since land endowments are measured in hectares in a source such as the Food and Agriculture Organization (1978), these land-output ratios calculated in dollars must be converted into hectares using imputed prices per hectare (derived from industry totals).

A third problem is that it is critical for estimation purposes that factor intensities and factor endowments be measured in the same units for each factor, although it is

not necessary that these units be consistent across all factors (usually it is impossible). Individual rows of the matrix equations are separable, and if factors are compared it is in dimension-less units.

A final problem is that when data are not available for all variables for the same year, extrapolation is necessary. The critical year is that associated with the **A** matrix; all other data must be obtained for that year. Extrapolation is facilitated when data for similar variables can be used for comparison. Extrapolation is more difficult when only sporadic values are available, and discretion must be used to construct progressions through time. In most cases, the latter is the situation faced with international data, so that measurement error can be a significant factor in empirical studies. In some cases, extrapolation is impossible, and data have to be used from different years. If this is necessary, endowment data must pre-date technology (**A** matrix) or trade data, because in this model production and trade follow from existing stocks of endowments, and technology data must pre-date trade data, because production and trade also follow from an existing state of technology. Both cases of "judgmental" and "impossible" extrapolation present themselves in the second essay for a few variables.

C. Conclusion

The best reference on data sources is Maskus (1991), and I do not plan to overlap his discussion, but indicate that the sources for my data are largely based on his recommendations. Other authors, such as Leamer (1984), also provide good

discussions of data sources. This section has been concerned with how to use the data once it has been collected, a discussion largely omitted in other empirical papers. This section concludes with Table 7 which presents a brief summary of the steps in constructing a data base.

Table 7
Steps in Constructing An HOV Data Base

Preliminary

- choose year, countries (including base country for **A** matrix and currency), factors, industries
- problems: concordance, extrapolation

A matrix

- no aggregation - Leontief inverse $(\mathbf{I} - \mathbf{B})^{-1}$ Input-Output Table
- aggregation
 1. "Use of Commodities by Industry" I-O Table
 - a. aggregate over commodities/industries
 - b. divide commodity inputs by total industry outputs to form **B** matrix
 - c. calculate $(\mathbf{I} - \mathbf{B})^{-1}$ matrix
 2. develop **b(w)** matrix
 3. calculate $\mathbf{A} = \mathbf{b(w)}(\mathbf{I} - \mathbf{B})^{-1}$ matrix
- may be problems in calculating land/output ratios
- factor/output ratios need to be in same units as in **V** matrix

V matrix

- collected for all countries in "world"
- capital most complicated - usually based on investment flows which must be:
 - a. deflated
 - b. depreciated - length of asset life?
 - straight-line or double-declining balance?
 - c. currency conversion - base country?
 - market exchange rates or purchasing power parity rates?

T matrix

- calculate imports from and exports to countries in "world" for separate industries, aggregate over trading partners

V. THE SIGNIFICANCE OF FACTOR PRICE EQUALIZATION IN EMPIRICAL WORK

In conducting an empirical analysis, attention must be paid to the assumptions of the theoretical model being used. A critical assumption of the Heckscher-Ohlin-Vanek model is that the countries have relative factor endowments which are not *too* dissimilar. Similarity of relative factor endowments is necessary in order to achieve factor price equalization (Samuelson (1949)). This assumption is especially critical for the expanded Heckscher-Ohlin-Vanek model since it assumes factor price equalization to begin with; the **2x2x2** Heckscher-Ohlin model has factor price equalization as a result.

However, the vast majority of the empirical papers in the Heckscher-Ohlin-Vanek model seem to have overlooked this assumption. This is puzzling since several well-known papers have drawn attention to factor price equalization, and the conditions under which it can be achieved, especially the requirement of similar relative factor endowments. Although all of these papers pre-date Vanek (1968), the significance of this assumption was apparent even for the basic model.

Heckscher (1919) is the first to discuss the idea of factor endowments not being too dissimilar in the context of the United States' trading position before the large European immigration. It was a great disparity in factor endowments that generated this factor migration, and therefore, similarity of relative factor endowments that is necessary in order for the assumption of immobile factors to hold.

Heckscher notes that factor price equalization is the result of trade, assuming there are fixed supplies of factors of production and there is the same technique of production in all countries. However, this is only the result if the disparity between amounts of (and returns to) factors is small enough to be compensated for by factor substitution within the same techniques of production. If discrepancies are too large, trade cannot equalize factor prices, and factor migration will be likely. Discrepancies that are too large prevent countries from being able to specialize in products which use their relatively abundant factor intensively in the most economical way, which is what occurred in the United States before the large European immigration when the severe scarcity of labor prevented the most efficient use of abundant land.

Samuelson (1949) discusses the conditions necessary to achieve factor price equalization. Although he does not develop the proof, he specifically states the assumption of similar relative factor endowments as necessary to achieve factor intensity uniformity, and thereby, factor price equalization in both the $2 \times 2 \times 2$ case and the case of many goods and factors. The reasoning here, which is similar to Heckscher's argument, is that similar relative factor endowments mean that all countries produce all commodities; i.e., there is no complete specialization by a country in a commodity. Complete specialization prevents factor price equalization from being achieved because there can be no substitution of factors in production, and therefore, factors cannot be used most efficiently. Factor substitution is the only way factor intensities can become uniform (each country uses factors in the same proportions to produce a particular good) and equalize factor prices.

Johnson (1957) discusses the impact of relative factor endowments in the context of the consistency of factor intensity rankings of commodities. As noted previously, the Heckscher-Ohlin-Vanek model predicts consistency in these rankings.

Using the $2 \times 2 \times 2$ case with the factors capital and labor, Johnson states that one of two possibilities may occur with respect to factor intensity rankings, depending upon the ease of substitutability of one factor for another in production. In the first case, when substitution is relatively difficult, one commodity will remain labor intensive and one capital intensive, no matter what the relative factor prices are. In the second case, when it is relatively easy to substitute capital for labor in the initially labor-intensive commodity, the difference in capital intensity of the two commodities will continually narrow, and eventually reverse. More than one reversal is also possible, as changes in relative factor prices induce changes in the capital intensity of production of the two commodities. Thus, the problem with which Johnson is concerned is factor intensity reversals. The relevance of this problem is that in order for factor intensity rankings to be independent of factor prices, making it possible to rank factors consistently following Heckscher-Ohlin-Vanek, there must be no factor intensity reversals.

Factor intensity reversals can be demonstrated with the use of figures 1 and 2. In this example, there are two countries (I, II), I is relatively labor (L) abundant while II is relatively capital (K) abundant; two commodities (X, Y), X is relatively L-intensive while Y is relatively K-intensive; and two factors labor (L) and capital (K).

Figure 1 depicts the case of no factor intensity reversals. The optimal K/L ratios for producing commodities X and Y are shown as r_X and r_Y , with r_Y always at a higher K/L ratio because Y is relatively K -intensive. The overall K/L ratios in countries I and II are given by r_I and r_{II} , with r_{II} always at a higher K/L ratio because II is relatively K -abundant. The autarky relative factor prices are given by w_I and w_{II} , where $w = p_L/p_K$, with w_{II} at a higher p_L/p_K ratio because labor is relatively more expensive where it is relatively scarce. The autarky relative commodity prices are given by c_I and c_{II} , where $c = p_X/p_Y$, with c_{II} at a higher p_X/p_Y ratio because it is relatively more expensive for II to produce X .

As these two countries open to trade, country I 's production process will become more K -intensive and w_I will rise, and it will specialize in X according to its relative abundance of labor (the opposite is true for country II). As a result, the relative factor prices will converge to w_{FT} as the relative commodity prices converge to c_{FT} . In this situation, the two countries follow the basic predictions of the Heckscher-Ohlin model. Trade results in factor intensity uniformity (both countries produce using the same K/L ratio for each commodity) and factor price equalization (a single w_{FT} and c_{FT}).

Figure 2 depicts the case of a single factor intensity reversal. The countries and factors are as before, but notice now that r_X and r_Y cross. While commodity X is initially L -intensive as before, at some set of relative factor prices it becomes

Figure 1. The Case of FPE with no FIRs

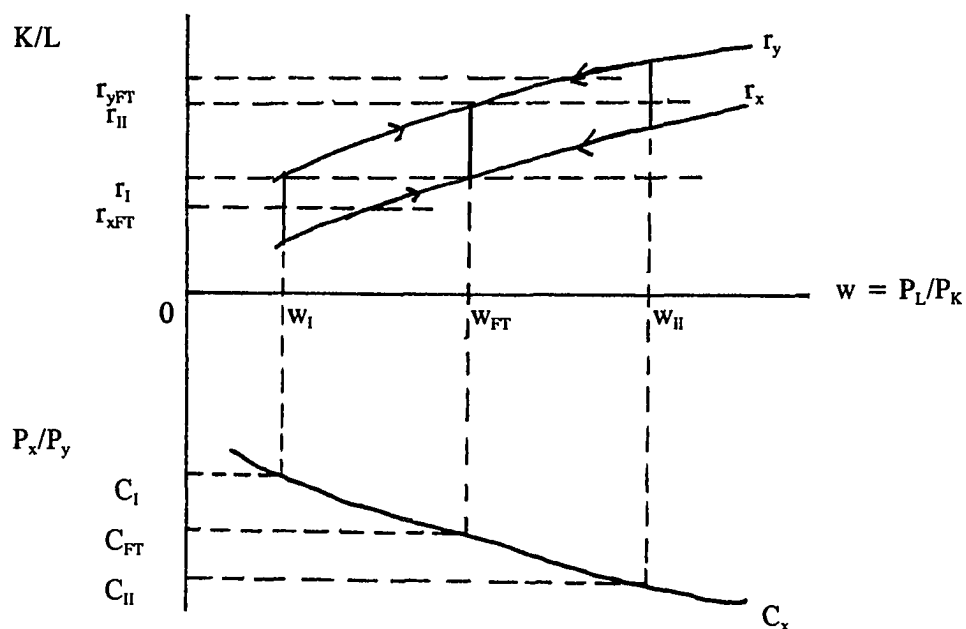
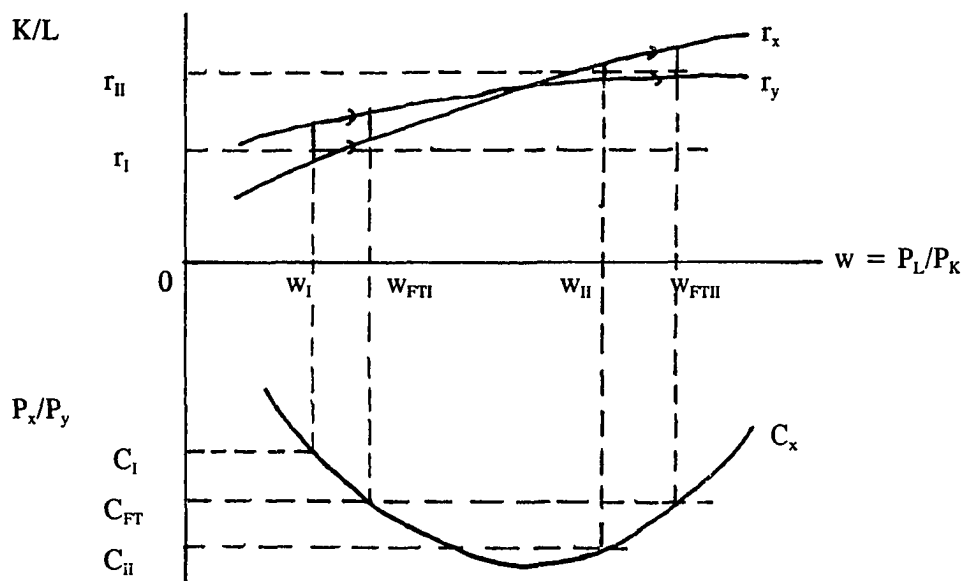


Figure 2. The Case of FIRs



K-intensive (the opposite is true for commodity **Y**). Now when the countries open to trade, the behavior of country **I** is consistent with Heckscher-Ohlin, but that of country **II** is not.

Country **I**'s production process becomes more **K**-intensive, w_I rises to w_{FTI} , and specialization is in commodity **X**. However, country **II**'s production becomes more **K**-intensive rather than **L**-intensive, so there is no factor intensity uniformity - factor intensities are diverging rather than approaching a single **K/L** ratio for each commodity. Country **II** specializes in **Y**, but **Y** is the **L**-intensive commodity at the free trade relative factor prices w_{FTII} , which are greater than w_{II} . The single set of free trade relative commodity prices c_{FT} yields two sets of relative factor prices, w_{FTI} and w_{FTII} .

Thus, country **II** does not behave according to the Heckscher-Ohlin predictions and there is no factor intensity uniformity, no one-to-one correspondence between commodity prices and factor prices, and no factor price equalization. Commodities can no longer be ranked consistently in terms of factor intensity for all possible relative factor prices. Heckscher-Ohlin breaks down in the presence of factor intensity reversals. The critical feature of Heckscher-Ohlin is the ability to rank commodities regardless of relative factor prices. This enables us to determine trade flows and specialization based solely on relative factor endowments. If factor intensities in production depend on relative factor prices, rankings are no longer price-insensitive, and the predictive power of Heckscher-Ohlin is lost.

Since there is no factor price equalization - an important assumption of the Heckscher-Ohlin-Vanek model - in the presence of factor intensity reversals, it is critical in empirical research to avoid circumstances in which factor intensity reversals are likely to occur. Johnson notes that factor intensity reversals are not likely if the relative factor endowments of the countries are sufficiently similar. He states that the Heckscher-Ohlin conclusions not only depend on the assumptions of the theoretical model, but also on empirical assumptions about the similarity of relative factor endowments (or the nature of technology affecting substitutability of factors).

Minhas (1962) discusses the empirical significance of factor intensity reversals using the (then new) constant elasticity of substitution (CES, or homohypallagic) production function, which allows both for elasticities of substitution to differ among industries and a single set of relative commodity prices to correspond to more than one set of relative factor prices. This production function allows Minhas to generate a situation of factor intensity reversals.

Minhas specifically addresses the issue of the similarity of relative factor endowments by examining the United States and Japan. If relative factor endowments are similar, then relative factor prices should be similar. His example of the United States and Japan is one of two countries with very different relative factor prices in the late 1940s. Minhas states that if there were no factor intensity reversals, then the United States and Japan should have identical rankings of industries in terms of factor intensities. Using data from 1947 U.S. and 1951 Japanese Input-Output Tables, he

shows that the rankings across industries are not consistent. His results are shown in

Table 8, adapted from Minhas (1962: 147).

Table 8
Ranking of Industries by Capital Intensity
Based on Total Capital and Labor Requirements

Industry	United States	Japan
Petroleum products	1	1
Coal products	2	2
Agriculture	3	20
Grain mill products	4	19
Processed foods	5	13
Chemicals	6	5
Non-ferrous metals	7	4
Iron and steel	8	3
Paper and products	9	11
Non-metallic mineral products	10	9
Textiles	11	15
Transport equipment	12	10
Machinery	13	6
Rubber and products	14	12
Shipbuilding	15	7
Lumber and wood	16	17
Industry (not elsewhere classified)	17	16
Printing and publishing	18	8
Leather	19	18
Apparel	20	14

This result suggests that factor intensities depend on relative factor prices (evidence of factor intensity reversals), rather than being established independently of relative factor prices as predicted by Heckscher-Ohlin.

Thus, Minhas demonstrates Johnson's result empirically, showing that large disparities in factor endowments lead to factor intensity reversals and a failure of Heckscher-Ohlin-Vanek to hold. He provides supporting evidence that factor endowment similarity is an important issue for empirical analysis.

This discussion leads to the conclusion that it is important for empirical studies of Heckscher-Ohlin-Vanek to be conducted in settings in which factor price equalization can reasonably be expected to be achieved if we are to attempt to test the theory on the type of world it hypothesizes. In the second essay, the choice of countries reflects the desire to obtain factor endowment similarity.

This discussion also suggests that the applicability of Heckscher-Ohlin-Vanek theory is extremely limited (as mentioned above). Given that the international field consists of partial theories rather than a single, more general theory, we may expect limited applicability. However, in this case such a limitation may be severe enough to render the theory virtually meaningless. In addition to this limitation, it may be that the failure to find empirical support suggests that the theory should be abandoned. In either case, we should first determine if the model's performance is improved if applied to a setting which more closely fits its assumptions.

VI. MOTIVATION FOR THE USE OF THE HECKSCHER-OHLIN THEORY

On the broadest level, several things are emphasized about the use of the Heckscher-Ohlin theory (and its extensions) in this dissertation. First, Heckscher-Ohlin theory may be a useful way of viewing part of the world's trading system. Relative factor endowments do play a role in determining trade flows. This is seen in the dominance of Heckscher-Ohlin as a theory of international trade, and in its use in other models, such as Helpman (1981), as part of a broader picture of world trade flows. That relative factor endowments play a role in influencing trade patterns is also seen empirically although the results have not in general been strong.

Second, and on the other hand, Heckscher-Ohlin in its strictest form as the only determinant of (net) trade patterns should not be expected to hold. Research on Heckscher-Ohlin using the Samuelson assumptions should be developed with an eye toward demonstrating the role played by relative factor endowments in explaining the complexities of the world trading system (as in Helpman (1981)). Net trade flows are regulated by relative factor endowments and comparative advantage; however, other features ruled out by Heckscher-Ohlin theory are also playing a substantial role.

The final point follows from the second, in that the theoretical limitations of Heckscher-Ohlin suggest empirical limitations for the Heckscher-Ohlin-Vanek model as well. The errors endogenous to the data concordance and the assumption of identical technology (among others) imply that the stronger tests of Heckscher-Ohlin-

Vanek are destined to fail.²³ It is unrealistic to expect regression analysis or the "strong" test (which requires a strict equality to hold) to provide good or meaningful results when the data used for analysis are real-world trade flows generated by more than differences in relative factor endowments. In fact, it is usually necessary to introduce other variables into a regression analysis of the Heckscher-Ohlin-Vanek model (beyond those of factor endowments, factor intensities, and trade) although this specific theory allows for no role for any other features. The impact of finding some other variable significant is unclear, since if other variables are introduced, it is now a broader model that is being tested. Therefore, the "weak" and "rank" tests better convey the principal message of the Heckscher-Ohlin-Vanek research agenda, which is to detect the influence of relative factor endowments in real-world trade data.

Further research within the Heckscher-Ohlin-Vanek agenda is characterized by Bensen and Elmslie (1992) as being consistent with the preservation of the hard core of neoclassical trade theory. While acknowledging that Heckscher-Ohlin-Vanek cannot explain all trade observed in the "real world", it is worthwhile to continue to investigate whether it can be empirically supported for the type of trade it was developed to explain (namely, interindustry trade between similarly developed countries).

The motivation for using Heckscher-Ohlin-Vanek in this dissertation is in itself multi-dimensional. First, as is explored further in the second essay, the introduction

²³ Brecher and Choudhri (1988: 5) note that, "[a]lthough some weak tests are favorable to the HOV [Heckscher-Ohlin-Vanek] model, now there is overwhelming evidence that the model is rejected when confronted with strong tests." This dissertation attempts to provide an explanation for these results.

of the environment as an influence on trade flows seems to be most appropriately made as a factor of production. As such, Heckscher-Ohlin-Vanek is a logical choice. Second, the use of the Heckscher-Ohlin-Vanek model provides an illustrative "test" of the benefits of making one's theoretical and empirical models consistent. It seems to have been straightforward enough to make the models consistent in form. What seems to have been overlooked to this point is the need to make the models consistent in assumptions. Heckscher-Ohlin-Vanek was designed to describe the workings of a long-run world, a world which must be matched (or at least approximated) in empirical applications. Finally, although perhaps incongruously, to set the stage for the third essay it is necessary to demonstrate that Heckscher-Ohlin-Vanek is probably not the best model for examining the interactions between trade and the environment. The limitations of the static, endowments-based, comparative advantage Heckscher-Ohlin-Vanek model in the face of the dynamic impact of the environment indicate a need to examine global ecosystems in a more complex setting.

I close this first essay with some observations of Ohlin (1967) which were made after he had the opportunity to reconsider Heckscher-Ohlin theory with the benefit of time. He shares (at least in spirit) my call to be aware of the limitations of the Heckscher-Ohlin theory.

In arguing the importance of integrating a mutual interdependence price theory (i.e., Walras' system) into a theory of international trade, Ohlin much prefers the factor proportions model (from Heckscher and modified by Ohlin) to the comparative cost model. However, while in 1933 Ohlin viewed factor proportions as the

foundation upon which to base a general theory of international trade, by 1967 Ohlin realized it is too incomplete to be a foundation. Rather, he views it as a "basic" model to be used to begin looking at international trade issues. Because of the complexities of international trade,

[i]t follows that not only the comparative cost model but also the factor proportions model can only be applied in special cases and used as a general introduction to illuminate the character of trade in some essential respects. ... Evidently both these theoretical models presuppose so many simplifying assumptions that they make up only a minor part of the fundamental theory of international trade. However, I maintain that the factor proportion [sic] model, built into the mutual interdependence system, is a better introduction than the comparative cost model. (Ohlin 1967: 309)

Ohlin goes on to discuss the many facets of trade not contained in the factor proportions model. Among those discussed, one important subject for which the factor proportions model is inadequate is the trade of developing countries because the assumption of all countries having all factors does not apply. For such countries, factor endowments may not be the sole motivation for trade. Thus, the Heckscher-Ohlin model may be appropriate only for developed countries. The factor proportions model is also inadequate to address issues of location and transport conditions.

However, Ohlin states that the factor proportions model can and needs to be extended to include the advantages of large-scale operations and different production functions. He also discusses other ways in which the model can be extended. Overall, the tone of the discussion is a warning not to ask too much of the factor proportions model, but to use it as the best alternative with which to examine some of the basics of trade.

SECTION 2

THE ROLES OF THE ENVIRONMENT AND FACTOR ENDOWMENT SIMILARITY IN AN EMPIRICAL HECKSCHER-OHLIN TRADE MODEL

This essay discusses an empirical application of the Heckscher-Ohlin model that includes the environment as a factor of production and emphasizes the importance of choosing countries that are similar in relative factor endowments. This essay follows the literature that attempts to improve the empirical performance of the Heckscher-Ohlin model by expanding the types of factors of production specified in the model. While these attempts have not been especially successful to date, a complete specification of the factors is desirable because it should increase explanatory power as the model more closely fits the real world. It is hypothesized that including the environment (in the form of pollutant emissions) will improve the empirical results because of the unique contribution that it captures, and the specific contribution of including the environment will be highlighted in the empirical tests.

Including the environment as a factor of production has been attempted in different types of empirical international trade models. Leonard (1988) presents a policy-oriented discussion rather than a formal economic model, and considers comparative advantage in terms of the assimilative capacity of various countries. Tobey (1990) follows Leamer (1984) and therefore does not conduct a complete test of the Heckscher-Ohlin-Vanek model; he incorporates the environment through a dummy variable representing the relative severity of environmental regulations. As Rauscher noted (1991: 29),

Recent empirical studies by Leonard [1988] and Tobey [1990] cast some doubt on the hypothesis that the abundance of environmental resources can explain a significant part of the patterns of international trade and factor movements.

There are (at least) four plausible explanations for these results: (1) the factor abundance theory of international trade is wrong, (2) the theoretical models are too simple, (3) the empirical studies did not measure the endowment of the economy with environmental resources correctly, and (4) these studies omitted important variables that cause the deviation of the empirical results from the postulates of economic theory. These hypotheses are on the agenda for future research.

Of the "plausible" explanations, (1) and (2) can be dismissed quickly by noting that the factor abundance theory is not wrong, but is a partial model in the sense that it can only describe part of world trade flows, and for this reason it may be perceived as too simple.¹ Explanation (4) is connected to the first two because a partial model of world trade flows only includes variables relevant to the type of trade it can describe. This leaves explanation (3) which highlights the contribution this essay makes by attempting to "correctly" treat the environment in the Heckscher-Ohlin-Vanek framework.

The other feature that this model emphasizes is the similarity of relative factor endowments among countries. As discussed in the first essay, this is a requirement that must be met in order for factor price equalization to be achieved, which is an important assumption of the Heckscher-Ohlin-Vanek model. This requirement was noted by both Heckscher (1919) and Samuelson (1949), but seems to have been overlooked in empirical studies which have chosen to allow the scope of the available data, rather than conformity with theory, dictate the countries analyzed. The empirical model developed in this essay takes this requirement into consideration by

¹ However, it is also the case that every international trade model is a partial model because of the complexities of international relationships, and might be faulted as being too simple.

choosing a small number of similarly-endowed countries. Consideration of this requirement makes this empirical model unique, and should serve to strengthen the empirical results.

I. BACKGROUND ON THE RELATIONSHIP BETWEEN THE ENVIRONMENT AND INTERNATIONAL TRADE

In order to justify the inclusion of the environment in an empirical Heckscher-Ohlin-Vanek model, it is necessary to discuss the role of the environment as a factor of production. For many reasons, it is certainly not as straightforward to view the environment as a factor as it is to view labor or physical capital as factors. Most notable, perhaps, as a reason for this difficulty is the fact that the use of the environment seems to be implicit because there is usually no price associated with it. Thus, we are dealing with the well-known problem of an externality.

Externalities are impacts on parties outside the scope of an economic transaction that are not compensated for if detrimental, nor paid for if beneficial. The use of the environment in production is expressed in terms of the pollution generated by the production process, at least part of which is an externality because the polluter does not adequately account for the cost of generating this pollution. The role of environmental regulation is to impose abatement and/or clean-up costs on the pollution generated in order to force the polluter to adequately account for the cost of polluting. Forcing an accounting for externalities is known as "internalizing" costs, and is the goal of environmental regulation. The idea is that if costs are internalized, both the producer and the ultimate consumer bear responsibility for the costs of producing polluting products.² Environmental government policy is necessary

² This concept is known as the "polluter pays principle" and is the guideline for environmental regulation adopted by Organization for Economic Cooperation and Development (OECD) member countries (Walter 1975, especially Chapter 5).

because market forces alone seem to be incapable of producing the correct price for pollution.

The fact that environmental regulations are the source (in large part) of the price for pollution as a factor may be why authors such as Tobey (1990) choose the regulations as a proxy for the environmental endowment. But this captures only part of the total impact on price. The availability of the environment as a factor depends not only on the state of regulations but also on the assimilative capacity of the area. Both of these influence the price associated with the use of the environment.

Assimilative capacity is the measure of the environment's ability to recover from the impacts of pollution. Although the actual biological and chemical relationships are far more complex, it is generally believed that a cleaner environment has a higher assimilative capacity than a dirty one - the first "units" of pollution are easier (or cheaper) to recover from than later ones. Assimilative capacity is related to the overall size of the area in question and the existing uses of the area, which are in turn related to things such as population density. Although assimilative capacity cannot be precisely measured, the concept has been discussed (see Leonard (1988)) as a proxy in a generalized model.

Note that both proxies are incomplete. The role of the environment as a factor in international trade can differ if countries have identical regulations but different assimilative capacities, or identical assimilative capacities but different regulations. In general, both will be different between countries. Both proxies also present difficulties for empirical work since they are virtually impossible to quantify. Thus,

the measure of the environment used in this model is incomplete and represents an approximate quantification. However, it attempts to incorporate the impacts of both regulation and assimilative capacity by using information on actual pollution generated in each country and the technological differences in pollution generation per unit of output in each industry.

Since the environment serves as a factor of production, and is a factor whose availability and cost may differ among countries, it can be fit into the Heckscher-Ohlin framework as a factor determining comparative advantage. Before doing so, it is worthwhile to examine the relationship between the environment and international trade.

Walter (1975) is one of the earliest analyses of the relationship between the environment (pollution) and international trade, and one of the leading contributors to the field.³ He discusses the concept of environmental assimilative capacity as a factor determining the comparative advantage of a country, and emphasizes its immobility. That is, unlike labor, if a country runs short of the environmental factor, it cannot import the factor. Its only option is to import goods that use the factor intensively. He also discusses differential environmental controls among countries and notes that the implementation of environmental policy must be done in a trade-neutral way so as to avoid retaliation through trade policy if environmental policies are interpreted as barriers to trade (trade-neutrality is one of the attractive features of

³ Walter clearly represents the focus of the writing in this area in the mid- to late 1970s. Other authors writing at the time acknowledge this role (see Gray 1976).

the "polluter pays principle"). As will be discussed shortly, more recent authors have also been concerned about the relationship between trade policy and environmental policy. Walter (1975) represents both the emergence of the environment (as opposed to natural resources) in discussions of international trade, and the most common interpretation of the role that the environment plays in trade.

Siebert and Antal (1979) discuss the relationship between the environment and international trade in much the same terms as Walter. However, they introduce a slightly different conception of assimilative capacity that seems useful in view of the reality of imperfect environmental data. Their notion of assimilative capacity expands upon the idea of a natural capacity to include demand factors. In particular, they note

[i]nstead of an assessment of environmental quality, the tolerable level of emissions can be used in the sense of the standard price approach, in other words, environmental policy determines the amount of emissions which exceeds the [natural] assimilative capacity of the environment and which the society is willing to accept. (Siebert and Antal 1979: 171)

Thus, assimilative capacity is measured in terms of the demand for assimilative services. This may offer another explanation for why Tobey (1990) relied on environmental regulations as a proxy, but probably better indicates that measures of both pollution produced and regulations should be considered.

Again in Siebert, et al. (1980) we find a similar discussion to those just mentioned. A useful clarification made here is the method of integrating pollution into production theory.⁴ Siebert, et al. explain that there are two approaches

⁴ This is not the only method possible. The literature on agricultural pollution discusses the social planner's problem where emissions can be a constraint on the maximization of total profits (Griffin and Bromley 1982) or where regulatory strategies are chosen to maximize environmental quality subject to a budget constraint (Sharp and Bromley 1979). For purposes of the Heckscher-

[o]ne approach treats pollutants as joint outputs of production activities (gross emissions approach). Abatement activities are explicitly introduced and resources are used for production as well as abatement. The alternative approach is more compact in integrating production and abatement into one activity and treating environmental services (wastes reception) as an input to the production function (net emissions approach). (Siebert, et al. 1980: 17)

For the purpose of integrating pollution into theoretical Heckscher-Ohlin-Vanek models the latter approach is primarily used, as environmental assimilative capacity is typically the input. However this is not always the case, and further detail is provided below in the discussion of theoretical Heckscher-Ohlin models that include the environment. Because assimilative capacity is virtually impossible to measure, in the empirical model I use a proxy based on the idea of treating a joint output as an input.

While the preceding articles discuss the relationship between environment and trade in economic terms, other more recent articles discuss the relationship in legal terms. Of primary interest to most authors is whether and to what extent the General Agreement on Tariffs and Trade (GATT) deals with environmental concerns in its prohibitions on trade restrictions.

Reinstein (1991) outlines the provisions of GATT that relate to interactions between trade and the environment. Perhaps not surprisingly, given that GATT entered into force in 1948, the document has little to say explicitly on the issue of the environment. The basic provisions of GATT are designed to promote free trade and prevent discriminatory practices among countries. GATT also promotes reciprocity

Ohlin-Vanek model, the emphasis on physical production means that pollution is more readily built into the technology matrix (and therefore the production function).

between countries and the transparency of trade barriers; the latter provision means (in part) that the preference is for tariffs over quotas or other types of quantity (rather than price) mechanisms.

Article XX of GATT contains the general exceptions to the requirements of the other Articles. These are nondiscriminatory measures that are inconsistent with other provisions, but which are permissible as long as they do not act as disguised trade restrictions. The environment is mentioned explicitly in this Article, in paragraphs (b) and (g). Reinstein (1991: 4) states that

[p]aragraph (b) specifies measures "necessary to protect human, animal or plant life or health" and paragraph (g) specifies measures "relating to the conservation of exhaustible natural resources if such measures are made effective in conjunction with restrictions on domestic production or consumption." It is worth noting that neither of these provisions specifies that the humans, plants, animals or resources must be in the country taking the trade-restrictive measure.

Reinstein (1991) goes on to discuss the different ways in which trade and environmental issues interact. One method of interaction is of interest in this essay because it is present in the relationships between the industrialized countries included in this study, namely, the trade effects of national environmental standards and regulations. Such standards and regulations may affect trade either directly or indirectly and therefore may lead to responses through the framework of GATT. As noted previously, the existence of environmental regulations affects the availability of the environment as a factor of production. The extent to which regulations differ among the countries in this study is discussed below. Reinstein notes that one response to differing national environmental regulations is to harmonize them internationally, the intent being to reduce their impact on trade. Whether this is

accomplished or not, Reinstein believes that environmental concerns should be a part of trade agreements.

Petersmann (1991) also discusses the relationship between GATT and environmental policy. He reaches the conclusion that "GATT-consistent instruments of environmental policy are likely to achieve the environmental policy objectives in a more efficient manner and to enhance a pattern of production and consumption minimizing pollution." (Petersmann 1991: 210) This is true because of the general preference for price, rather than quantity, incentives to reduce pollution on efficiency grounds and because GATT-consistent measures would be politically attractive. He notes several recent actions that suggest that parties to, and rules being made under, GATT are increasingly concerned with the environment. "As both environmental and trade policies aim at the efficient use of world resources, environmental and trade rules should be mutually supportive." (Petersmann 1991: 219) He argues for working through the GATT framework to address environmental concerns rather than attempting to avoid GATT because of the general acceptance and efficiency of GATT procedures. He does, however, note that the full ramifications of the relationship between trade and the environment have not yet been worked out.

The literature on the interactions between the environment and international trade is growing. The sense one gets from most authors is that in order to properly account for environmental impacts, a broader view of what international trade involves is necessary. As van Bergeijk (1991: 112) states, "[t]he environmental challenge then is to reconcile traditional 'economic' comparative advantage and

environmental comparative advantage, the latter linking the desired global pattern of specialization to minimizing the costs to the environment." The present essay is a timely investigation of a growing concern. It is clearly important in our policy discussions to support desired actions with empirical evidence - which is what this essay intends to provide.

II. STRUCTURE OF THE MODEL

This section lays out the structure of the empirical model, emphasizing three unique features. First is the introduction of the environment as a factor of production. The inclusion of this variable in the empirical setting requires an examination of the theoretical models in order to determine the method of introduction and the expected results. Second is the regulatory setting of the study. In order to determine whether environmental regulations might have an impact on the results, it is necessary to look at the countries and the time period under study and the state of existing regulations. Third is the attention paid to the requirement of factor endowment similarity. This discussion provides part of the justification for the group of countries studied, as meeting this requirement is critical to fulfilling an important assumption of the Heckscher-Ohlin-Vanek model. Finally, this section concludes by discussing the small empirical record on the environment in international trade models.

A. Environment as a Factor of Production

I hypothesize that including the environment as a factor of production will improve the empirical performance of the Heckscher-Ohlin-Vanek model, by resulting in a more complete specification of the factors of production. As Siebert (1991: 5) notes, the environment does have a place in this model:

like other traditionally recognized factors, such as resources, technical know-how, and so on, environmental abundance or scarcity is a factor in trade that should be included in determining comparative advantage.

Rauscher (1991) adds that as long as transfrontier pollution (pollution that crosses national boundaries) is negligible, including the environment (in the form of pollution) in this type of model does not make any significant changes to trade theory - meaning that the (national) environment fits the concept of a factor of production as used in Heckscher-Ohlin theory. Thus, I must assume that the detrimental effects of transfrontier pollution are negligible, as this model requires that factors are immobile internationally and are associated with a particular country.⁵ In the Heckscher-Ohlin framework, pollution is indirectly transferred internationally.

In order to address environmental factors, the theoretical adaptation necessary is a particular specification of the elements of V (and, by necessity, A) in equation [1] presented in the first essay, and reproduced here:

$$[1] \quad AT_k = V_k - s_k V_w.$$

Attempts to theoretically incorporate the environment (often as pollution) into the Heckscher-Ohlin framework include Walter (1974), Pethig (1976), and especially McGuire (1982) whose work I follow most closely. As an interesting aside, in this section I also briefly discuss Merrifield (1988) which deals with the problem of transnational pollution in a general equilibrium framework.

⁵ The concern of this model is that there is a lack of economic incentives for factors to move. In general, the movement of pollution is due to physical, rather than economic, forces.

Walter (1974)⁶ presents a graphical illustration of a Heckscher-Ohlin model that incorporates the environment in the form of environmental assimilative capacity. Environmental assimilative capacity (EAC), the response of environmental quality to increments of effluents (hence output), is an immobile productive resource which enters into the determination of comparative advantage. This is a resource whose distribution varies internationally, so Walter states (but does not derive) the expected result of a Heckscher-Ohlin model, "EAC-abundant countries tend to export goods whose production involves greater pollutive discharge - although it becomes operational only if EAC is indeed priced." (Walter 1974: 486)

His model demonstrates that engaging in environmental management means a diversion of resources away from the production of tradable goods and towards the production of non-tradable environmental control. At the same time, consumption of tradables, exports, and imports are all reduced when resources are diverted in this manner. Walter goes on to consider the fact that the relative impacts on production, consumption, exports, and imports of resource diversion depend on the factor intensity of environmental controls (the production of non-tradables). That is,

resource-diversion into environmental management influences the relative gains from trade - negatively if environmental control uses intensively those productive resources on which a country's comparative advantage is based, and positively if the reverse is true - which in turn will increase or offset its cost to society in terms of conventional goods and services. (Walter 1974: 492)

⁶ This model was preceded by a more general discussion in Walter (1972) of the impact of environmental controls on international competitiveness; the ideas in these papers were collected in Walter (1975).

Pethig (1976) develops a generalized comparative advantage model which can generate Ricardian (trade based on different production technologies) or Heckscher-Ohlin results. This model treats emissions of pollutants as the environmental factor of production, a specification designed to measure the physical capacity of the environment as a waste receptor. Pethig is primarily interested in the impact of environmental controls which are the enforcement of standards to limit emissions.

In Pethig's model, two goods (1,2) are produced using only labor. Each industry produces its output and a by-product which is of no use in either consumption or production, so it is released into the environment. This by-product (emissions) can be interpreted as a factor of production,⁷ so the production functions are specified with two factors - labor and emissions. The model is specified so that good 1 is relatively environment (emissions)-intensive and good 2 is relatively labor-intensive.

Pethig considers the concept of environmental assimilative capacity by specifying a function that describes how emissions are turned into pollution. There are no pollutive effects until an assimilative capacity is exceeded, once exceeded pollution increases at an increasing rate with emissions until an upper limit on pollution is reached, at which point ecological collapse occurs triggering a breakdown in the economy.

For two countries not yet experiencing environmental degradation (referred to as developing countries) which require no environmental controls to be enforced,

⁷ Baumol and Oates (1971) are the source of this interpretation.

labor is the only effective factor of production because the supply constraint on environmental services has not been reached. The results generated are Ricardian - the country that specializes on the environment-intensive good may suffer a welfare loss from trade, while the country specializing on the labor-intensive good always gains from trade. The welfare loss occurs if the welfare loss from decreased environmental quality outweighs the welfare gain from increased quantities of goods 1 and 2 through trade.

Countries facing severe environmental pollution are referred to as industrialized and are assumed to be enforcing environmental controls. In trade between two so-defined industrialized countries, Pethig takes into consideration the intensity of their environmental controls. In this case, Heckscher-Ohlin results are reached where the country with the less restrictive environmental controls specializes on the production of the environment-intensive good, and there is no welfare loss from trade for either country. In this model, there are no requirements or expectations that the environmental qualities in the two countries are the same before or after implementation of controls because the environmental goals of the two countries may differ.⁸

Pethig's model demonstrates that trade between industrialized countries has a Heckscher-Ohlin character. In addition, Pethig's definition of industrialized is one

⁸ Pethig's model can also be used to discuss the issue of the environmental impacts of trade between industrialized and developing countries (as he defines them).

that fits the countries in my study, all of which are putting pressures on the environment and have environmental regulations of some type.

Before discussing McGuire (1982), it is interesting to look briefly at Merrifield (1988) which deals with the problem of transnational pollution flows. Working within the Heckscher-Ohlin framework, as mentioned above, the only type of pollution that can be considered is that which is generated and has its impacts within national boundaries. In a different type of general equilibrium framework one can consider pollution which crosses national boundaries, and therefore is directly transferred internationally. Merrifield specifically deals with these transnational pollution flows, and develops a model that incorporates the feedback effects of pollution on the production process along with the more general effects of pollution.

The model has two countries, each of which produces and exports one of two composite goods. There are two factors - labor and capital; the pollution feedback serves to increase the scarcity of capital services, but has no impact on labor.⁹ Pollution and capital are both mobile internationally, while labor is not. The production of both goods generates emissions, and as a result, pollution abatement equipment is employed in both industries. The focus of the analysis is on the impact of abatement strategies (on prices and the movement of goods and capital) which is operationalized by looking at governmental requirements concerning the ratio of pollution abatement equipment to output.

⁹ This of course ignores the often important detrimental health impacts of pollution.

The comparative static results of this rather complex model are for the most part ambiguous with regard to abatement strategies. The two main strategies for pollution control are standards and taxes - an equipment standard unambiguously reduces pollution, while a tax could increase pollution if one country's emissions reduction is more than offset by increases in the other country's output and emissions due to capital movements.

The overall conclusion of this analysis is that when open economies are faced with controlling transnational pollution, what appear to be effective abatement strategies in the closed economy case are no longer necessarily effective when followed unilaterally. Merrifield's model captures features quite different from the other articles discussed here, and demonstrates that there are many dimensions to the pollution problem.

The theoretical model that has most influenced my work is that developed by McGuire (1982). The primary difference between this model and those just discussed is the treatment of the environment variable. McGuire uses the basic Heckscher-Ohlin framework with two countries **A** and **B**, two factors **L** and **K**, and two goods **X** and **Y**.¹⁰ He then makes the argument for introducing the environment as a factor of production in this framework:

From one perspective pollution is an unwanted by-product or output from offending industrial processes. From another logically equivalent point of view, however, the environment is a factor of production which is 'used up' in industrial and agricultural processes. (McGuire 1982: 337)

¹⁰ The notation has been changed slightly to conform to that used in the rest of the dissertation.

McGuire introduces the environment (**E**) as a factor in the production of good **X** only, where the usage (depletion) of the environment is measured as a physical quantity of effluent output.¹¹ Thus, the two production functions are:

$$X = F(L_x, K_x, E) \quad \text{and} \quad Y = G(L_y, K_y).$$

The focus of his analysis is on the impact of regulation on the use of the environment in the production process. In the absence of regulation the price of polluting is zero (which must mean that the externality effect of pollution is being ignored).

Therefore, in a perfectly competitive industry, the marginal cost of using the environment is zero. When regulation is imposed on the production of **X** to limit the use of the environment as a factor, there will be less **X** produced. If the reduction is proportionate for every **L-K** combination so that **L** and **K** intensities remain the same, the effect of regulation is equivalent to negative neutral technical progress. The type of regulation that accomplishes this is one that constrains the level of pollution to a minimum allowable marginal product (at some level above that equivalent to a price of zero).

In the Heckscher-Ohlin framework, McGuire considers the impact of different environmental regulations of the form described above in the two countries. When the two countries coordinate their environmental controls, all of the results of the Heckscher-Ohlin model hold, especially those of factor intensity uniformity and factor price equalization. However, if environmental controls are not coordinated, such as

¹¹ In the long-run sense of the Heckscher-Ohlin-Vanek model, factor supplies are equal to factors used.

the extreme of one country imposing regulation and the other not, the factor price equalization result is destroyed.

The latter case provides an incentive for factor mobility. If factors are permitted to move, McGuire derives the result that the regulating country will be driven out of the production of the regulated good. In that case, unilateral environmental regulation can be effective if the impact of pollution is felt only nationally.

McGuire (1982) has an impact on my research in two ways. First is his interpretation of the environmental factor as the output of pollutant emissions. Although the other theoretical models use environmental assimilative capacity as a factor, the output of emissions is more appropriate if one intends a model to be estimable. This is because assimilative capacity is a theoretical concept which cannot be adequately quantified. I follow McGuire to provide a theoretical foundation for the use of emissions in an empirical setting. However, I modify McGuire's approach by introducing the environment as a factor of production in every industry, rather than just one.

The second impact McGuire has had on this essay is his emphasis of the effect of regulation on trade flows. This would tend to affect the amount of emissions generated, and is thus implicitly included in the quantitative measure of emissions. In addition, I consider the existing state of regulations in the countries in this study.

In order to justify McGuire's interpretation of the environmental factor theoretically, one can think of effluent output or emissions as an indicator of the

"political will" to allow pollution in a country. "Political will" is often expressed through the existence and severity of environmental regulations. A country that has a strong will to allow emissions will tend to exhibit a higher level of them (holding such things as preferences and environmental assimilative capacity constant). "Political will" can therefore reflect public (and environmental) tolerance for emissions.

McGuire does not give an elaborate justification for his treatment, stating (as noted above) that such a treatment is logically equivalent to conceptualizing emissions as a joint output of production.¹² Empirically there is justification for using emissions, which are really outputs, as measures of endowments, as will be seen below.

The introduction of the environment adds to the list of factors typically considered. Therefore, in the present model the vector of factor endowments V_k in equation [1] includes high skill (L^H_k) and low skill labor (L^L_k)¹³, capital (K_k), agricultural (N^A_k) and forest land (N^F_k), all of which are factors of production typically found in empirical work, and environment (E_k).

B. Influence of Environmental Regulations

In order to assess the impact of the environment on international trade, it is necessary to evaluate existing pollution and regulations. However, with respect to

¹² Again, this interpretation is based on the discussion in Baumol and Oates (1971).

¹³ High skill labor is professional, technical, administrative, and managerial workers (categories 0/1 and 2). Low skill labor is clerical, sales, service, agricultural, and production workers (categories 3, 4, 5, 6, and 7/9).

regulations, it is difficult to compare programs across countries because of differences in such things as governmental structure and implementation plans. Therefore, it is not as useful to provide details of the various countries' regulations as it is to examine secondary sources¹⁴ that have attempted to compare regulations in terms of severity and other features. The purpose of this discussion is to get a sense of the state of regulations at the time of the study to determine whether differential regulations have an important impact on trade patterns.

Siegel and Weinberg (1977) examined all types of public policies, including those relating to pollution control, in eight countries in the mid-1970s (the time period of my study). They ranked those countries' pollution-control policies from strongest to weakest as follows: Sweden, United States, France, East Germany, Great Britain, West Germany, Soviet Union, and Italy.¹⁵ In their evaluation,

[s]trong policies involve such elements as large subsidies, user charges that are not routinely passed on to consumers, lead or consolidated environmental agencies, the support of local governments and major interest groups, and a broad approach to environmental impacts. (Siegel and Weinberg 1977: 411)

They argue that there is a common pattern to the development of national environmental programs that is strongly related to the process of industrialization. This enables them to focus on the characteristics listed above as signals of a level of "maturity" of environmental policies. It also enables them to make the fairly common argument that environmental regulations are an impediment to the economic progress

¹⁴ Such sources were able to conduct more comprehensive studies of environmental regulations than was possible here.

¹⁵ Of these, Sweden, East Germany, and the Soviet Union are not included in my study, although Canada and Japan are.

of developing countries. That is, a country must achieve a certain level of industrialization before it can afford to consider environmental impacts.

Although Siegel and Weinberg produce their ranking based on these particular characteristics, other authors' assessments of the environmental programs of the countries in my study are roughly comparable. The drawback of these assessments is that they are rankings, so that while they may suggest some difference between countries they say nothing about the magnitude of any difference.

Walter and Ugelow (1979) report a ranking derived from a survey of environmental policies conducted by the United Nations Conference on Trade and Development (UNCTAD) in 1976. The ranking places countries' policies on a range from tolerant to strict, based on the rigor of the policies. Tolerant suggests that a country has no significant environmental policies, while the strict ranking uses the United States as the benchmark because

federal air and water quality legislation and administrative measures placed the US centrally within a "cluster" of OECD countries that had the most cohesive and tight environmental policies of all countries surveyed. Moreover, US policies were highly articulated and readily available, thus providing a convenient yardstick for international comparisons of this type. (Walter and Ugelow 1979: 106)

While UNCTAD did not provide rankings for all countries in my study,¹⁶ with reference to the United States benchmark West Germany is ranked as moderate to strict, Japan as strict, and the United Kingdom as moderate. It is difficult to assess the distinctions in the rankings or any meaning therefrom.

¹⁶ Many of the European Community (EC) countries included in my study were not listed separately, but gathered under an EC listing. UNCTAD indicated that EC-wide policies were in the process of development.

Walter and Ugelow indicate that there are a variety of features to be considered in constructing environmental policy, and note that countries differ in how they incorporate these features. For instance, a country such as Japan utilizes centralized, as opposed to decentralized, authority; Italian administrative structures are more fragmented than comprehensive; and, West Germany allocates environmental costs primarily to consumers rather than tax-payers. In addition, control of policy is primarily in the executive branch in France, but in the legislative branch in Canada, and the United Kingdom prefers to take a "case-by-case" approach while the United States prefers a "blanket" approach.

These differences are influenced by the social priorities in a country, as well as the structure of the government and the political process. Therefore, the strength or effectiveness of a program is not determined by the choice of elements per se, but by whether the choices fit within the structure a particular country is accustomed to using. Thus, we again have a ranking that suggests some differences among countries, but does not indicate the magnitude of these differences.

In addition to differences in the framework of environmental policies, the social priorities and state of the local environment in various countries influence whether programs target all environmental problems, or perhaps just air or water problems. For reasons of data availability, in the empirical analysis I have focused on air pollution from industrial (stationary) sources and the countries in my study differ in their air pollution programs and the degree to which air pollution is a problem. Walter (1975) has a brief discussion of air pollution programs which suggests that

Japan, the United Kingdom, and the United States had fairly strong programs in the early 1970s, West Germany's and Canada's programs were somewhat less strong, and France and Italy had the weakest programs of the group. It is difficult here as well to get an idea of the magnitude of the differences among countries.

The conclusion to be reached from this brief attempt to assess the state of environmental regulations at the time of my study is that there appear to be some differences among this group of countries, but it is difficult to know the impact such differences will have because their magnitudes cannot be measured. The manner in which differential regulations are likely to have their influence is in interfering with the performance of the environment variable, which is based on levels of pollution and existing technologies but only indirectly on the effects regulations have on industries. An attempt will be made to assess the nature of this impact in the analysis of results below.

C. Factor Endowment Similarity

As discussed in the first essay, I consider the implications of an often overlooked assumption of the Heckscher-Ohlin-Vanek model in my analysis. As noted by both Heckscher (1919) and Samuelson (1949), in order to achieve factor price equalization - an assumption of the Heckscher-Ohlin-Vanek model - countries must not be too dissimilar in relative factor endowments. The countries chosen for analysis - Canada, France, West Germany, Italy, Japan, the United Kingdom, and the United States - seem to fit such a description for 1977 (the year chosen for analysis)

and provide a world in which factor price equalization can reasonably be expected to be achieved.

Table 9 below shows the rankings of relative abundance of the six factors included in this study for each of the seven countries. The rankings are calculated based on factor endowment ratios, which are the ratios of the country's endowment of the factor (F^i_c) to the world's (all seven countries) endowment (F^i_w). These ratios are used in order to have dimensionless quantities for comparison. In this table, the measure of capital used is that based on the double-declining balance depreciation method and market exchange rates. Environment is measured as industrial (stationary) source emissions of all major air pollutants: sulfur oxides, nitrogen oxides, hydrocarbons, carbon monoxide, and particulates.¹⁷

Table 9
Rankings of Relative Factor Abundance

	K	N^A	N^F	L^H	L^L	E
Canada	4	2	1	5	6	3
France	1	5	6	2	3	4
West Germany	1	5	6	3	2	4
Italy	4	5	6	3	1	2
Japan	2	6	4	3	1	5
United Kingdom	4	5	6	2	1	3
United States	5	1	4	3	6	2

where: **K** is capital, **N^A** is agricultural land, **N^F** is forest land, **L^H** is high skill labor, **L^L** is low skill labor, and **E** is environment.

These rankings demonstrate a certain degree of similarity among the countries, more so for particular pairs of countries (such as France and West Germany) and

¹⁷ The rankings in Table 9 are based on Tables 10 and 12 which are discussed below.

more prominent for certain factors. Overall we would not expect identical rankings because of the geographical, political, and other differences among the countries. The expectation is that these countries are similar enough.

Conducting the analysis in a setting of similar relative factor endowments is designed to avoid the problems derived theoretically by Johnson (1957), and demonstrated empirically by Minhas (1962), of factor intensity reversals and the lack of a one-to-one correspondence between commodity and factor prices which both destroy factor price equalization. Although this is arguably of lesser importance empirically than theoretically when the analysis involves the use of Input-Output Tables,¹⁸ the inconclusive results reached so far demand that we consider all possible problems in empirical research.

D. Previous Empirical Results

There are two recent attempts to empirically evaluate the impact of the environment in a comparative advantage or Heckscher-Ohlin framework, Leonard (1988) and Tobey (1990). The few other empirical studies that exist are not in a comparable framework. This small empirical record is not unexpected - it is very difficult to develop a measure of the environment variable that can be used in the Heckscher-Ohlin analysis. In fact, as discussed above, it is very difficult to develop a measure of the environment for any type of analysis. Given that assimilative capacity

¹⁸ The methodology of Input-Output Tables involves many restrictive assumptions, including the fixed-coefficients technology which is a built-in feature of the tables. This is just one of the limitations of a static analysis.

is virtually impossible to measure, the only other options are proxies of various types. These two papers are especially weak in addressing the environmental variable. An examination of these two studies should help to clarify the changes that will be made in my work.

Leonard (1988) is an attempt to assess two complementary theories of industrial location with regard to environmental regulation: the industrial-flight and pollution-haven hypotheses. These two theories seek to explain the impact of environmental regulations on the existing allocation of comparative advantage in industrial production. The industrial-flight hypothesis states that strict environmental regulations will push an increasing number of industries out of advanced industrial nations, while the pollution-haven hypothesis states that less-developed countries will attract multinational industries because of lenient environmental regulations.

Leonard characterizes these hypotheses as establishing comparative advantage, however, his concept of comparative advantage is not that of the Heckscher-Ohlin model, but one developed in the process of bringing together elements of five different theories, all of which help to explain industrial location. The theories are those relating to: the product life cycle in manufactured goods; foreign direct investment; industrial location decisions; industrial development strategies for nations; and, bargaining processes between corporations and national governments. He defines his concept as a description of "the array of social, economic, and political forces that account for the general export and import patterns prevailing between nations." (Leonard 1988: 8)

Leonard uses the case of the United States to examine whether environmental regulations have pushed U.S. industries abroad, and looks at four rapidly industrializing countries to determine whether following a pollution-haven strategy encourages industrial development. The data used to evaluate these hypotheses are statistics on changes in investment and trade patterns within and between the United States and certain industrializing nations for particular industries, and information on the motivations behind these trends on the part of multinationals and governments. Both are necessary to determine whether environmental regulations have been the source of changes in industrial location.

In order to evaluate comparative advantage, Leonard considers a measure of the environment endowment in terms of a country's natural and social assimilative capacity to deal with industrial waste. Using Leonard's conceptualization, a country with unused assimilative capacity is environment-abundant, while a country that has reached or exceeded its assimilative capacity is environment-scarce. However, in Leonard's analysis this concept is never actually quantified. The impact of the environmental factor is merely suggested in the selection of countries (and industries) that are analyzed.

The analysis includes consideration of such features as: the pollution-intensity of production; whether the impacts of pollution are felt nationally or transnationally; national versus international environmental regulations; and, the international mobility of factors of production. It is the last feature that primarily differentiates this study

from an analysis based on Heckscher-Ohlin. For this reason, his results are more illustrative than directly applicable to my work.

Leonard discusses how the idea of a comparative advantage in the environment and the related industrial production pollution impacts influenced policy-makers, especially with regard to the industrial-flight and pollution-haven hypotheses. He examines statistical data in order to determine whether there is support for the intense political and theoretical debates that arose concerning the impacts of environmental regulation.

Leonard notes the difficulty of separating out the impact of environmental regulation on industrial location, especially in the type of analysis he is conducting (without formal modeling). There are many factors that influence the location and re-location of industries that must be isolated in order to determine whether patterns that appear to be influenced by environmental regulations in fact are. Isolation of factors is difficult when analyzing data by observation rather than through regression.

Upon examination of trade and investment data for the United States for the chemicals and mineral processing industries - industries determined to be relatively pollution-intensive - Leonard draws the following conclusion with respect to the industrial-flight hypothesis.

Taken in the aggregate, the investment and trade figures...indicate that the years immediately following emergence of stringent environmental regulations [1970s and 1980s] in the United States did not witness widespread relocation of pollution-intensive industries to countries with drastically lower regulatory requirements. (Leonard 1988: 115)

He finds that although some industries are choosing to leave because of environmental controls, they are not being driven out, but are just in too weak a financial state to deal with the costs of environmental regulations.

Leonard's assessment of the pollution-haven hypothesis is based on case studies of four representative countries outside the core of industrialized countries. These are Ireland and Spain, representing less-industrialized capitalistic countries in Europe that have attracted U.S. direct investment; Mexico, representing the newly industrializing countries; and Romania, representing the rapidly industrializing socialist countries in Eastern Europe. These countries each dealt with the pollution issue differently in the 1970s and 1980s because of different political and economic circumstances, but they are all the type of country that is the focus of the pollution-haven hypothesis.

In Ireland, although the trend in the early 1970s had been to attract industry with a willingness to accept the pollution because it meant jobs, by the late 1970s and 1980s the decision had changed to put a higher priority on the environment and be more selective about the types of industries that would be encouraged. In contrast, although Spain did encourage industrial investment during the 1970s, it was not because it offered itself as a pollution haven. Economic concerns were the overriding motivation for encouraging industrial development, despite the fact that Spain already had very serious pollution problems, and environmental concerns did not play an explicit role. While environmental concerns may not have been a prominent feature in Mexico's industrial strategy in the 1970s and 1980s, they were at least one component of the attractiveness of Mexico to U.S. firms - in addition to proximity

and the *maquiladora*¹⁹ program. While officially Romania gives the environment high priority, its actions during the 1970s suggest some evidence of the pollution-haven idea. Leonard concludes on the basis of these four countries that there is little evidence to support the pollution-haven hypothesis as a strategy for industrial development.

The overall conclusion of Leonard's study is that environmental regulations are not a decisive factor in industrial location decisions. He finds no support for either the industrial-flight or pollution-haven hypotheses, and he also finds that environmental factors neither detract from nor enhance industrial comparative advantage. However, he adds that this does not mean that environmental factors play *no* role in these decisions. What it does indicate is that

the differentials in the costs of complying with environmental regulations and in the levels of environmental concern in industrialized and industrializing countries have not been strong enough to offset larger political and economic forces shaping aggregate international comparative advantage. (Leonard 1988: 231)

Leonard's study does not truly analyze a Heckscher-Ohlin model, but uses the idea of comparative advantage loosely drawn from that model to characterize a case study of a small group of countries analyzing the impact of the environment on industrial location. There is no rigorous formal model, which prevents Leonard from being able to isolate the impact of the environmental factor in his analysis. In fact his conclusions suggest that this impact is indeed masked by the impacts of a host of other factors.

¹⁹ *Maquiladoras* are assembly plants located in northern Mexico which are controlled by multinational firms and which process imported materials and components for export, primarily to the United States.

The difference between Leonard and the present study is that I introduce formal modeling to provide a more rigorous means of assessing the impact of the environment. The model chosen rules out the mobility of factors considered by Leonard. Also, this study focuses on industrialized countries because, as noted in the first essay, the Heckscher-Ohlin framework is not appropriate for use with developing or industrializing countries. Therefore, the industrial-flight and pollution-haven hypotheses could not be analyzed in the framework of the present study.

Tobey (1990) is an example of a formal Heckscher-Ohlin analysis of the impact of the environment that uses the Heckscher-Ohlin-Vanek model in its basic form and with two extensions. The introduction of the environment into the model is accomplished through the use of a qualitative variable that represents the stringency of pollution control measures in a particular country. The analysis also involves the examination of error terms when this variable is not included.

Tobey defines the pollution intensity of commodities in terms of the pollution abatement costs incurred in production. Pollution abatement costs reflect the levels of regulation and enforcement, and the state of technology. Measures of these costs for certain²⁰ Input-Output Table industries are multiplied by the total expenditures Input-Output Table to generate estimates of pollution abatement costs (direct and indirect) per dollar of output for each industry. The year of analysis is 1977.

²⁰ Tobey uses measures generated for sixty-four two-digit agricultural and manufacturing industries.

Tobey is interested in defining pollution intensity because he only uses the most polluting industries in his analysis. These are defined as industries whose pollution abatement costs are at least 1.85 percent of total costs - a cut-off that corresponds to those industries commonly considered the most polluting (mining, steel, nonferrous metals, paper, and chemicals). These industries have pollution abatement costs in the range of 2 to 3 percent of total costs - note that this is still a relatively small percentage of total costs. In terms of the countries examined, he includes both developed and developing countries.

As discussed in the first essay, there are four ways in which the Heckscher-Ohlin-Vanek equations have been empirically estimated. Two methods use measures of factor intensities and trade flows to infer factor endowments - the factor content studies and cross-commodity regressions. One method uses measures of trade flows and factor endowments to (implicitly) infer factor intensities - the cross-country studies. The last method uses independent measures of all three - trade flows, factor endowments, and factor intensities - and is considered a complete test. Tobey, however, mentions only the first three methods, and chooses to use the third, following Leamer (1984).

Tobey defines the same factor endowments as Leamer, using 1975 data for capital, three kinds of labor, four types of land, coal, minerals, and oil. He specifies his equation as follows:²¹

$$T_{jk} = \alpha_j + \beta_{j1}V_{1k} + \dots + \beta_{j11}V_{11k} + \epsilon_{jk}$$

²¹ The notation used here has been chosen to correspond to that used in this dissertation.

where: (1) T_{jk} is net exports of commodity j from country k ; and

(2) V_{nk} is the endowment of factor n ($n = 1$ to 11) in country k .

The coefficients in this equation represent the effect of a change in a factor on net exports of a commodity; at least part of this has been interpreted by other researchers as consisting of the impact of factor intensities.

The impact of the environment is tested for in two ways. The first is by including a qualitative environment variable in the equation. The idea behind the second method is that if the environment does play a role and is left out of the equation above, the problem is to be treated as a specification error involving an omitted variable. Both methods are appropriate for cases in which a quantitative measure of the environment is not available.

The first method introduces a qualitative variable measuring the stringency of pollution control measures in a country as an additional regressor. This variable is based on the rankings found in Walter and Ugelow (1979), which are (as discussed above) fairly uninformative. An ordinary least squares estimation of the above equation including the qualitative variable produces strong R^2 values (0.9 or greater) for the five equations representing the five highly polluting industries, but t values for the coefficients on most of the regressors are not statistically significant (suggesting the existence of multicollinearity or few degrees of freedom). Tobey notes only that the coefficients on the environmental policy variable in the five equations are not statistically significant.

The second way to determine the impact of the environment is to conduct an omitted variable test, which is an examination of the bias in the regression residuals of the above equation with no environment variable included. While a detailed discussion of this methodology is not provided here, these results also suggest that pollution control measures have no impact on net exports of commodities as in the above equation. However, since the environment variable is not significant when it is in the equation, it is questionable to attribute any bias to pollution control measures.

In addition, Tobey conducts analyses that involve extensions of the basic Heckscher-Ohlin-Vanek model following Leamer (1984). Few details are provided on these analyses, but he does summarize the results. The first extension allows for non-homothetic preferences, which Tobey finds pertinent because of the use of countries at different stages of development, but which does not produce results that find environmental controls to have an impact on net exports. The second extension allows for scale economies and product differentiation, but is not strictly based on Heckscher-Ohlin theory, and again does not provide support for the idea that pollution controls influence trade flows.

Thus, the overall conclusion of Tobey's study is that the empirical results do not support the theoretical results, that is, pollution control measures do not have an impact on trade flows in a regression analysis of the Heckscher-Ohlin-Vanek model. However, there are a number of problems with Tobey's analysis that diminish the strength of his conclusions. First, Tobey only analyzes pollution-intensive industries. While intuitively one might expect any impacts of pollution to be displayed most

prominently with such industries, by leaving out other industries Tobey reduces the variation in the data used for the regressions (although the distinction between pollution-intensive and not pollution-intensive is quite small). Heckscher-Ohlin-Vanek is expected to hold over all industries.

Second, Tobey uses both developed and developing countries in an Heckscher-Ohlin-Vanek setting. As discussed in the first essay, because of the nature of the assumptions of Heckscher-Ohlin theory, the model is only appropriately used on a group of countries similar in relative factor endowments, and best fits industrialized countries. Third, Tobey appears to discount the contribution of Bowen, Leamer, and Sveikauskas (1987) and the importance of conducting a complete test. Finally, Tobey's analysis of his empirical results is not very critical and raises questions about his interpretation of results. In all, Tobey's is a flawed attempt at empirically analyzing the impact of the environment in the Heckscher-Ohlin-Vanek setting.

The difference between Tobey and the present study is that I introduce a quantitative measure of the environment and use a group of industrialized nations. The present study is also based on the complete test of the Heckscher-Ohlin-Vanek model. These changes in the context of a formal analysis should generate stronger results (whether supporting or refuting) with respect to the impact of the environment on trade flows. The present study is designed to contribute specifically to the Heckscher-Ohlin-Vanek literature on the subject.

III. EMPIRICAL APPLICATION OF THE HECKSCHER-OHLIN-VANEK MODEL

The content of the first essay, and the second essay to this point, has been the arguments for the development and analysis of a particular empirical model. We are now ready to work with this empirical model. As much as possible, duplication will be minimized by making reference to the discussions in the first essay of data and statistics.

A. Data

Since the first essay provided information on how the various data sources are used, the discussion here and in the data appendix (Appendix A) will be limited to listing the specific sources for the variables used in my study. I follow Bowen, Leamer, and Sveikauskas (1987) in formulating a complete test approach, with the use of some data suggestions from Leamer (1984), Maskus (1991), Sveikauskas (1984), and others. Formulating a complete test requires the concordance of data across SIC and SITC industries, resulting in the aggregation of many industrial categories. Even with aggregation, there are imperfect matches, especially since industry definitions may not be consistent across countries. Therefore, much reliance is made on the data sources adapted for previous empirical work and available concordances. The most significant restriction made is to use only manufacturing industries, as data and data concordances are more readily available for the manufacturing sector of the economy.

The source for the concordances used in this study is Maskus (1991). The details on the sources are found in the data appendix.

The data sources are used to create the variables for the various equations - C_k , C_w , F^i_k , F^i_w , and F^i_{xk} . Table 10 summarizes the last three of these variables in creating the two measures of relative factor abundance. The first is the factor content measure which is the ratio of F^i_{xk} to F^i_k , or the ratio of the factor content of net exports to country k 's endowment of the factor. The second is the factor endowment measure which is the ratio of F^i_k to F^i_w , or the ratio of country k 's endowment of factor i to the world's endowment of factor i . These measures are used to create the rankings for the "rank" test. Notice that since the factor content measure is based on net trade flows, it can take on both positive (net export) and negative (net import) values. A large net export value is ranked more highly than any net import value; large net import values are ranked lowest.

Table 10 provides data for rankings for four alternative measures of capital which differ in terms of the method of depreciation of the investment stream - double-declining balance or straight-line - and in terms of the conversion rates used - purchasing power parity (PPP) or market exchange rates. The different capital measures generate some differences in the rankings created. While comparisons among factors and countries are facilitated by using rankings, one piece of information of interest from this table is that upon examination of the factor endowment measure one can see that the United States dominates the rest of the countries in this seven-country world in every factor. This is primarily a function of

Table 10. Measures of Factor Abundance

Factor Content Measure¹

<u>Factor</u> ^{2,3}	<u>Canada</u>	<u>France</u>	<u>West Germany</u>	<u>Italy</u>	<u>Japan</u>	<u>U.K.</u>	<u>U.S.</u>
K₁	-.0032	-.0044	.0037	.00254	.0054	-.0076	-.0036
K₂	-.0027	-.0037	.0030	.0022	.0042	-.0064	-.0030
K₃	-.0033	-.0044	.0032	.0037	.0053	-.0107	-.0036
K₄	-.0028	-.0037	.0026	.0031	.0041	-.0090	-.0030
N^A	.0010	.0474	-.1303	-.0342	-.5603	-.0452	.0070
N^F	.0456	.0157	-.3714	.0801	-.4130	-1.4268	-.0180
L^H	-.0178	-.0073	.0080	.00248	.0108	-.0065	-.0020
L^L	-.0182	-.0087	.0027	.0095	.0067	-.0062	-.0048
E	.0088	-.0257	.0199	-.0045	.1317	-.0097	-.0109

Factor Endowment Measure⁴

<u>Factor</u>	<u>Canada</u>	<u>France</u>	<u>West Germany</u>	<u>Italy</u>	<u>Japan</u>	<u>U.K.</u>	<u>U.S.</u>
K₁	.0544	.0928	.1280	.0465	.2142	.0576	.4064
K₂	.0528	.0902	.1265	.0446	.2267	.0558	.4032
K₃	.0541	.0938	.1480	.0322	.2223	.0412	.4082
K₄	.0525	.0911	.1461	.0309	.2350	.0398	.4045
N^A	.1150	.0548	.0227	.0300	.0095	.0316	.7364
N^F	.4863	.0217	.0108	.0094	.0371	.0031	.4317
L^H	.0472	.0895	.0931	.0348	.1305	.0823	.5224
L^L	.0376	.0810	.1049	.0864	.2322	.1023	.3556
E	.0898	.0595	.0849	.0389	.0280	.0783	.6206

¹ Abundance as expressed in the factor content of net trade flows. This is evaluated as the ratio F_{ik}^i/F_k^i , where F_{ik}^i is the content of factor i in country k 's net exports and F_k^i is country k 's endowment of factor i . (Negative sign indicates net imports).

² There are four alternative measures of capital considered: two evaluated at PPP rates (K_1 and K_2) and two at market exchange rates (K_3 and K_4); these also represent two different depreciation schemes - double-declining balance (K_1 and K_3) and straight-line (K_2 and K_4).

³ The environment is measured as stationary source emissions of all major air pollutants: sulfur oxides (SO_x), nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), and particulates.

⁴ Abundance as expressed in the factor endowment. This is evaluated as the ratio F_k^i/F_w^i , where F_k^i is country k 's endowment of factor i and F_w^i is the world's endowment of factor i . The world consists of the seven countries included in this study.

the United States being much larger than all of the other countries, and may have an impact on the results.

With respect to the environment variable, the proxy being used is the output of emissions.²² As discussed in the data appendix, this is limited to air pollutant emissions because of the inability to aggregate over different types of pollution. Emissions are used to capture the contribution of the environmental factor as they represent the use of the environment in production. While environmental assimilative capacity is discussed in the theoretical literature as the variable in which we are in fact interested, it remains a theoretical concept given our current state of knowledge. Therefore, any environmental variable is necessarily a proxy to this. Following McGuire (1982) on the use of emissions, the only type for which adequate data could be found were air pollutants. For the countries included in the study, air pollution should be a similarly important issue and thus serve as an appropriate illustration of the role the environment plays in influencing trade flows.

B. Statistics

Both nonparametric statistics and regression analyses have been applied to the relationships between net exports, factor intensities, and factor endowments. The fact that the Heckscher-Ohlin-Vanek theorem postulates a strict equality and linear relationship between factors embodied in net exports and factor endowments, a rather

²² A measure of emissions density (emissions divided by non-agricultural, non-forest land area) did not alter the results obtained below. It may be that a different concept of density would have an impact; this is a topic for future research.

unrealistic requirement, is one reason why the relationships may satisfy sign or rank nonparametric tests, but not fit the "strong" nonparametric tests or expected regressions well.²³ The first essay provided a detailed discussion of the development and properties of the "weak" (or sign), "rank", and "strong" tests, so the review of the three nonparametric tests below is brief.

The Bowen, Leamer, and Sveikauskas (1987) sign test (an adaptation of the Maskus (1985) "weak" test) simply compares the signs of the values on either side of the equality in equation [2] presented in discussion of the first essay, and reproduced here:

$$[2] \quad F_{\mathbf{xk}}^i = F_{\mathbf{k}}^i - (C_{\mathbf{k}}/C_{\mathbf{w}})F_{\mathbf{w}}^i \quad \text{for each country } \mathbf{k}.$$

From the Heckscher-Ohlin-Vanek theorem we expect the sign on the net exports of a factor to be the same as the sign on the excess supply of that factor. The test involves computing the proportion of sign matches between the two sides of the equation; this computation is performed for each of the factors, and for each of the countries, in the study.

The significance of the sign test can be evaluated using Fisher's exact test as calculated by Bowen, Leamer, and Sveikauskas (1987).²⁴ This significance test evaluates whether the signs of the values on either side of the equality are independent of one another or related, in an attempt to determine if agreement in sign between the

²³ Other explanations include the problems of data availability and concordance, as well as "white noise" errors.

²⁴ One source for a description of this test is Ostle (1963).

factor content of net exports and the excess supply of the factor is coincidental. The probability that the signs are independent is calculated using the grid below:

		Excess Supply of Factor	
		+	-
Factor Content of Net Exports	+	a	c
	-	b	d

Independence exists if $\frac{a}{(a+b)} = \frac{c}{(c+d)}$ and is evaluated using:

$$P_1 = \frac{(a+b)!(c+d)!(a+c)!(b+d)!}{a!b!c!d!n!}$$

where $n = a + b + c + d$.

One begins by choosing a critical value, say $\alpha = .10$, for the test. To calculate the statistic for Fisher's exact test, one evaluates a sum of P_i 's from $i = 1$ to $i = a+1$, where successive P_i 's involve decreasing a and d by one unit and increasing b and c

by one unit (stopping when $a = 0$). The null hypothesis that $\frac{a}{(a+b)} = \frac{c}{(c+d)}$, or

independence, is rejected if the sum of the P_i 's is less than or equal to the chosen α .

However, one only needs to calculate the first additive term, P_1 , if its value exceeds the value chosen for α .

The intuition here is that independence is represented by exact equality, but there is a range of inequalities around this which would be considered statistically close to equality. The value of α establishes the outer boundary of this range. If the sum of the P_i 's is less than (or equal to) α , then the inequality is too far away from equality to suggest independence. In such a case one can establish that a relationship exists between the values.

The Maskus (1985) "rank" test is based on the definition of relative factor abundance from the relationship between factor endowments and net exports of a factor derived from equation [2]; that is, factor i is abundant relative to factor j if and only if net exports of factor i as a share of country k 's endowment exceed net exports of factor j as a share of country k 's endowment:

$$F_{xk}^i/F_k^i > F_{xk}^j/F_k^j,$$

which should correspond to country k 's endowment of factor i as a share of the world's endowment ranking higher than its relative endowment of j :

$$F_k^i/F_w^i > F_k^j/F_w^j.$$

For an individual factor, comparing two countries, a similar relationship holds:

$$F_{xk}^i/F_k^i > F_{xk'}^i/F_{k'}^i.$$

This inequality indicates country k is abundant in factor i relative to country k' . This should correspond to country k 's relative endowment of factor i ranking higher than that of country k' :

$$F_k^i/F_w^i > F_{k'}^i/F_w^i.$$

Thus, for each country and factor, the relative factor abundance ranking of net factor exports as a share of the country's factor endowment should be identical to the ranking of a country's factor endowment as a share of the world's endowment. That is, the ranking of factor i using F_{xk}^i/F_k^i (the factor content measure of abundance) should be identical to the ranking of factor i using F_k^i/F_w^i (the factor endowment measure of abundance). Bowen, Leamer, and Sveikauskas (1987) indicate that they

test the correspondence of these rankings using Kendall rank correlation (actually Kendall's tau).

In my test of ranking correspondence I use Kendall's coefficient of concordance.²⁵ This statistic (W) measures the extent to which members of a set of r distinct rank orderings of c things tend to be similar (show concordance). With the data in a table with r rows and c columns, W_j represents column j 's total. If there were complete agreement in the rankings, $W_j = r*j$; if there were complete disagreement, $W_j = W_{j'}$ for $j \neq j'$. Thus, W measures the extent of the variability among the respective sums of ranks (W_j 's). W represents the ratio of the variance of rank sums to the maximum possible variance of rank sums and is calculated as:

$$W = \left\{ \frac{12 \sum_j W_j^2}{r^2 c (c^2 - 1)} \right\} - \frac{3(c + 1)}{(c - 1)}$$

where $0 \leq W \leq 1$, and higher values indicate greater consistency of rankings. The probability distribution of W approximates a Fisher's z distribution where

$$z = \frac{1}{2} \ln \left\{ \frac{(r - 1)W}{(1 - W)} \right\}$$

with $v_1 = c - 1 - \frac{2}{r}$ and $v_2 = (r - 1)v_1$ degrees of freedom (Kendall and Gibbons

(1990)).²⁶

²⁵ Kendall's tau and coefficient of concordance are similar; the latter allows for more than two rankings to be compared simultaneously. I prefer the intuition of the latter since it ranges from 0 to 1, in contrast to tau which ranges from -1 to 1. One source describing these statistics is Winkler and Hays (1975).

²⁶ Critical values of Fisher's z distribution were obtained from Fisher and Yates (1953).

In the present study, Kendall's coefficient of concordance is used to compare the two rankings (the factor content ranking based on F_{jk}^i/F_k^i and the factor endowment ranking based on F_k^i/F_w^i) for each factor over all countries and for each country over all factors. Thus, $r = 2$ and c equals the number of countries in the first case or the number of factors in the second case. An illustrative table for each case is diagrammed below:

<u>Capital</u>	Canada	France	W.Germany	Italy	Japan	U.K.	U.S.
factor content	1	2	3	4	5	6	7
factor endowment	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>
W_j	2	4	6	8	10	12	14

would yield $W = 1$

<u>U.S.</u>	Capital	Agr. Land	Forest Land	Skilled Labor	Unskilled Labor	Environment
factor content	1	2	3	4	5	6
factor endowment	<u>6</u>	<u>5</u>	<u>4</u>	<u>3</u>	<u>2</u>	<u>1</u>
W_j	7	7	7	7	7	7

would yield $W = 0$

In the first hypothetical case evaluating capital over the seven countries, the ranking using the factor content measure and the ranking using the factor endowment measure are identical for every country. Thus, $W = 1$ indicating complete concordance. In the second hypothetical case evaluating the United States over the six factors, the factor content ranking and the factor endowment ranking are completely opposite for every factor. Thus, $W = 0$ indicating no concordance. The typical cases lie somewhere between these extremes, with some agreement in rankings. The probability distribution for W is used to establish the degree of confidence one can have in the results.

The Maskus (1985) "strong" test is based on an equality condition from the Heckscher-Ohlin-Vanek theorem that if a country has balanced trade in some factor, the country's expenditure per unit of that factor's endowment must equal the world's expenditure per unit of that factor's endowment. Alternatively, if a country has positive net exports of a factor, the world's expenditure per unit of that factor's endowment must be larger; if negative net exports, the world's expenditure must be smaller. For this "strong" test, equation [2] is rewritten as:

$$[4] \quad \frac{C_w}{F_w^i} = \frac{C_k}{F_k^i} \left[\frac{1}{\left(1 - \frac{F_{zk}^i}{F_k^i} \right)} \right].$$

This test involves computing the percentage deviations between the actual values of C_w/F_w^i and those predicted by the right-hand side of equation [4]. Thus, it is simply a test of the degree to which the equality condition fails to hold. It is considered to be stronger than the "rank" test because the requirement of meeting this equality is a more stringent requirement than meeting a rank ordering. The shortcoming of the "strong" test is that there is no statistic associated with it to be used to judge how close is "close enough".

The regression analyses of the Heckscher-Ohlin-Vanek equations have produced poorer results than the nonparametric tests (see the discussion of Bowen, Leamer, and Sveikauskas (1987) in the first essay). Regressions have been performed on an adaptation of equation [1] excluding A (Leamer (1984)). The matrix system, combined with a GNP identity, constitutes a reduced form of equation [1] in Leamer's

interpretation.²⁷ Regressions have also been performed on a modification of equation [2] (a single row from the matrix system) that allows for some or all of the assumptions of the Heckscher-Ohlin-Vanek model to be relaxed. As noted in the first essay, relaxing the assumptions means that the elements of other theories, in addition to Heckscher-Ohlin-Vanek, are being tested.

Some differences between the two approaches are whether net trade in commodities or the factor content of net trade is the dependent variable, and whether the independent variables characterize supplies of endowments or excess supplies of endowments. The complete approach is one that utilizes the information contained in all three variables, which means using equation [1] or [2] in its original form, but the literature contains no cases of regressions of this type (without additional assumptions built in. One contribution of this essay is to use the complete approach and compare regressions performed on equation [2] in its original form to those of slight modifications of equation [2]. Studies such as Bowen, Leamer, and Sveikauskas (1987) perform regressions only on equations which incorporate relaxations of the major assumptions of the model.

C. Results

The results discussed in the text are for the complete data set, including the environment variable (E). The results obtained when the environment variable is

²⁷ There are a few researchers that have chosen to adapt equation [1] and regress T on A, omitting V (Bowen and Sveikauskas (1992)).

omitted are discussed in Appendix B. The discussion of results begins with the nonparametric tests. Tables 11 and 12 provide the results of the sign test and the "rank" test. The results for the "strong" test are presented later in Table 13.

The Heckscher-Ohlin-Vanek theorem tells us that in order for a country to be a net exporter of a factor, it must have an excess supply of that factor, and vice versa. The column labeled Sign in Tables 11 and 12 indicates the proportion of matches between the sign on net exports of a factor and the sign on the excess supply of the same factor, which is a comparison of the signs of the values on either side of the equality in equation [2]. The difference between the two tables is whether the test is being evaluated for a factor (Table 11) or for a country (Table 12). For example, in Table 11 the proportion of sign matches is .428 for E (environment). This means that of the seven equations [2] for E, one for each of the seven countries, three had signs that matched on either side of the equality.²⁸ In contrast, the proportion of sign matches is .857 for N^A (agricultural land). Of the capital measures, the proportion of sign matches is the same for K₁ and K₂ (based on PPP rates) and for K₃ and K₄ (based on market exchange rates). In Table 12, the proportion of sign matches is .500 for Italy, indicating that of the six equations [2] for Italy, one for each of the six factors, three had signs that matched on either side of the equality. In contrast, the proportion of sign matches is .833 for Canada and the United Kingdom. Obviously

²⁸ This low proportion may suggest a strong interference being reflected from environmental regulation in some countries.

Table 11. Ranking of Factors Across Countries¹

Factor²	Canada	France	West Germany	Italy	Japan	U.K.	U.S.	W³	Sign⁴
K₁, K₂ F.C.	4	6	2	3	1	7	5		
F.E.	6	4	3	7	2	5	1	.5893	.714
K₃, K₄ F.C.	4	6	3	2	1	7	5		
F.E.	5	4	3	7	2	6	1	.5714	.571
N^A F.C.	3	1	6	4	7	5	2		
F.E.	2	3	6	5	7	4	1	.9286 ^a	.857
N^F F.C.	2	3	5	1	6	7	4		
F.E.	1	4	5	6	3	7	2	.6428	.714
L^H F.C.	7	6	2	3	1	5	4		
F.E.	6	4	3	7	2	5	1	.7143 ^d	.428
L^L F.C.	7	6	3	1	2	5	4		
F.E.	7	6	3	5	2	4	1	.7678 ^d	.714
E F.C.	3	7	2	4	1	5	6		
F.E.	2	5	3	6	7	4	1	.3571	.428

¹ The Heckscher-Ohlin-Vanek theorem states that the factor content and factor endowment measures of abundance should provide consistent rankings of an individual factor across countries.

² F.C. - factor content measure ranking; F.E. - factor endowment measure ranking. Also see footnotes 2 and 3 to Table 10. Factors are grouped together if they generate identical rankings.

³ Value of Kendall's coefficient of concordance; $0 \leq W \leq 1$. ($r = 2$, $c = 7$). **a** indicates statistically significant at .01 level. **d** indicates statistically significant at .20 level.

⁴ Proportion of sign matches.

the desired proportion of sign matches is 1.000, and these results do not provide very strong support for the Heckscher-Ohlin-Vanek theorem on the basis of the sign test.

The significance of the sign matches is evaluated using Fisher's exact test. The result is that in no case can the null hypothesis of independence between the signs of the values on either side of the equality in equation [2] be rejected. In other words, the fact that there are any sign matches at all is coincidental. On this basis, there is no support for the Heckscher-Ohlin-Vanek theorem using the sign test. This fact should suggest that none of the other nonparametric tests will produce significant results since the sign test is purportedly the weakest of the nonparametric tests used. However, Bowen, Leamer, and Sveikauskas (1987) generated poor results with the sign test, but somewhat better results with the "rank" test, so this supposition may not be correct.

There are two versions of the "rank" test examined here. The first, shown in Table 11, is based on a ranking of each of the factors across the seven countries in the study. The second is based on rankings of each of the countries across six factors, including E, in Table 12. The rankings in these two cases are established based on the values in Table 10. The Heckscher-Ohlin-Vanek theorem indicates that the factor content and factor endowment measures of relative factor abundance should provide consistent (identical) rankings for factors across countries and for countries across factors.

Table 11 presents the rankings for each factor across the seven countries and the values for Kendall's coefficient of concordance (W) for each pair of rankings.

Table 12. Ranking of Countries Across Factors - Including E¹

Country ^{2,3}		<u>K</u>	<u>N^A</u>	<u>N^F</u>	<u>L^H</u>	<u>L^L</u>	<u>E</u>	<u>W⁴</u>	<u>Sign⁵</u>
Canada	F.C.	4	3	1	5	6	2		
	F.E.	4	2	1	5	6	3	.9714 ^a	.833
France	F.C.	3	1	2	4	5	6		
	F.E.	1	5	6	2	3	4	.3143	.583
W.Ger-1	F.C.	3	5	6	2	4	1		
	F.E.	1	5	6	3	2	4	.7428 ^d	
W.Ger-2	F.C.	4	5	6	2	3	1		
	F.E.	1	5	6	3	2	4	.7143 ^d	.667
Italy-1	F.C.	3	6	1	4	2	5		
	F.E.	2	5	6	4	1	3	.5428	
Italy-2	F.C.	4	6	1	3	2	5		
	F.E.	2	5	6	4	1	3	.4857	
Italy-3	F.C.	3	6	1	4	2	5		
	F.E.	4	5	6	3	1	2	.4571	.500
Japan-1	F.C.	4	6	5	2	3	1		
	F.E.	2	6	4	3	1	5	.6286	
Japan-2	F.C.	4	6	5	2	3	1		
	F.E.	1	6	4	3	2	5	.6000	.667
UK-1	F.C.	3	5	6	2	1	4		
	F.E.	4	5	6	2	1	3	.9714 ^a	
UK-2	F.C.	2	5	6	3	1	4		
	F.E.	4	5	6	2	1	3	.9143 ^b	
UK-3	F.C.	4	5	6	2	1	3		
	F.E.	4	5	6	2	1	3	1.0000 ^a	.833
US	F.C.	3	1	6	2	4	5		
	F.E.	5	1	4	3	6	2	.6857	.667

¹ The Heckscher-Ohlin-Vanek theorem states that the factor content and factor endowment measure of abundance should provide consistent rankings of an individual country across its factors.

² F.C. - factor content measure ranking; F.E. - factor endowment measure ranking. Also see footnotes 2 and 3 to Table 10.

³ For some countries, the way in which **K** was measured changed the ranking, thus the differing results are presented. West Germany-1 (**K**₁, **K**₂, or **K**₃), West Germany-2 (**K**₄); Italy-1 (**K**₁), Italy-2 (**K**₂), Italy-3 (**K**₃ or **K**₄); Japan-1 (**K**₁, **K**₂, or **K**₃), Japan-2 (**K**₄); UK-1 (**K**₁ or **K**₄), UK-2 (**K**₂), UK-3 (**K**₃).

⁴ Value of Kendall's coefficient of concordance; $0 \leq W \leq 1$ ($r = 2$, $c = 6$). **a** indicates statistically significant at .01 level. **b** indicates statistically significant at .05 level. **d** indicates statistically significant at .20 level.

⁵ Proportion of sign matches.

Each W represents the degree of concordance between the factor content and factor endowment rankings. The rankings for capital depend on whether PPP or market exchange rates are used. For E (environment), $W = .3571$ indicating that the two rankings are not very similar (since W ranges from 0 to 1). On the other hand, $W = .9286$ for N^A (agricultural land) which indicates that the two rankings are virtually identical; this value of W is statistically significant at the .01 level. Other statistically significant (at the .20 level) values for W are obtained for the comparisons of the rankings for L^H (high skill labor), $W = .7143$, and for L^L (low skill labor), $W = .7678$. The remaining values of W are greater than .5, suggesting that overall the rankings of factors across countries show some support for the Heckscher-Ohlin-Vanek theorem.

Table 12 presents the rankings for each country across the six factors (including E) and the W values for each pair of rankings. As in the previous table, some differences in rankings are generated depending upon how capital is measured, so some countries have multiple pairs of rankings. France has a $W = .3143$, indicating little similarity between the rankings based on factor content and factor endowment measures. However, all three of the W values for the United Kingdom are greater than .9 (one is equal to unity) and statistically significant at least at the .05 level. These suggest almost perfectly identical rankings for the United Kingdom. The $W = .9714$ for Canada is highly significant, and the W values for West Germany are also statistically significant. Other than Italy, the remainder of the countries have

high W values, suggesting overall moderate support for the Heckscher-Ohlin-Vanek theorem on the basis of the "rank" test.

One explanation for the large difference in the strength of the results between the sign and "rank" tests may be that the "rank" test does not require the information provided by the C_k and C_w variables, which is included in the sign test. In other words, the "rank" test abstracts away from the Heckscher-Ohlin-Vanek equations while the sign test is actually based on the full equations. This is related to points made in the first essay with respect to what we can expect of the Heckscher-Ohlin-Vanek model applied to real world trade data. One way to further examine this point is to compare the results of these tests to the results of the "strong" test which is based on the information in the full equations.

The "strong" test results are presented in Table 13. This test involves comparing actual values of C_w/F_w^i (from the data) to predicted values calculated from the right-hand side of equation [4], and computing the percentage deviations between these two values. Table 13 presents two sets of percentage deviations - the difference between them depends on whether GNP values are calculated using PPP or market exchange rates. Since, following the literature, C (consumption) is specified as being equal to GNP minus net exports, the C_k and C_w values differ slightly depending on the conversion rate used. There are some substantial differences in the percentage deviations, especially for the land and environment variables, but there is also quite a bit of variation among the countries.

Table 13. "Strong" Test - C_k , C_w Based on Market or PPP Rates¹

Country/ Factor				Country/ Factor				Country/ Factor			
% Deviation				% Deviation				% Deviation			
<u>Market</u> <u>PPP</u> ²				<u>Market</u> <u>PPP</u>				<u>Market</u> <u>PPP</u>			
Canada	K ₁	-12.5	-14.3	France	K ₁	0	-3.1	W.Ger.	K ₁	-4.1	-23.0
	K ₂	-9.2	-11.0		K ₂	2.9	-0.1		K ₂	-2.9	-21.7
	K ₃	-12.0	-13.7		K ₃	-1.0	-4.2		K ₃	-20.4	-42.2
	K ₄	-8.6	-10.3		K ₄	2.0	-1.1		K ₄	-18.9	-40.5
	N ^A	-136.9	-140.7		N ^A	44.0	42.3		N ^A	79.1	75.2
	N ^F	-856.6	-872.0		N ^F	76.4	75.6		N ^F	88.0	85.8
	L ^H	1.0	-0.5		L ^H	3.4	0.3		L ^H	24.7	11.0
	L ^L	21.2	19.9		L ^L	12.4	9.9		L ^L	14.6	-0.5
E	-83.2	-86.9	E	34.6	32.6	E	32.2	19.9			
Italy	K ₁	9.4	36.0	Japan	K ₁	-30.5	-38.4	UK	K ₁	4.2	29.6
	K ₂	12.9	38.5		K ₂	-38.3	-46.7		K ₂	7.5	32.0
	K ₃	37.2	55.7		K ₃	-35.5	-43.6		K ₃	31.3	49.5
	K ₄	39.7	57.5		K ₄	-20.8	-52.0		K ₄	33.7	51.3
	N ^A	39.3	57.2		N ^A	90.9	90.4		N ^A	45.6	60.0
	N ^F	83.1	88.0		N ^F	67.9	66.0		N ^F	87.7	91.0
	L ^H	32.0	52.0		L ^H	20.9	16.1		L ^H	-36.4	-0.3
	L ^L	-67.2	-17.4		L ^L	-40.7	-49.3		L ^L	-70.0	-24.4
E	23.5	46.0	E	80.3	79.1	E	-30.2	4.3			
US	K ₁	11.4	9.2								
	K ₂	12.2	-2.5								
	K ₃	11.0	8.8								
	K ₄	11.9	-2.9								
	N ^A	-58.8	-62.8								
	N ^F	4.6	2.2								
	L ^H	-13.7	-16.6								
	L ^L	-22.7	20.8								
E	-36.6	-40.2									

¹ C = GNP - Net Exports; equation used is [4] in text. Percentage deviation reported is $(\text{predicted } C_w/F_w^I - \text{actual } C_w/F_w^I) / \text{predicted } C_w/F_w^I$, expressed as a percent.

² Indicates whether market exchange rates or purchasing power parity rates were used to calculate C_k and C_w .

Since there has been no significance test developed for the "strong" test, it is not possible to evaluate how different from zero these deviations can be and still suggest support for the Heckscher-Ohlin-Vanek theorem. At best, the "strong" test here is inconclusive; at worst, it confirms the poor results of the sign test. In this respect, it does seem to indicate that using the full Heckscher-Ohlin-Vanek equations demonstrates how poorly the theory fits real world trade flows.

The basic regression results are presented in Tables 14 and 15. In the regressions, the full data set (all seven countries and all six factors) is used, in contrast to the nonparametric tests which are conducted on individual factors or countries. The Heckscher-Ohlin-Vanek equations predict the same structural form for all factors and countries so the data can be used in this way. The results for four different models are shown; each model has four versions which vary by the measure of capital used (and therefore, by whether PPP or market exchange rates are used to calculate C_k and C_w). Table 14 presents the first two models which involve estimating the following equation:

$$[A] \quad F_{xk}^i = \beta_0 + \beta_1 F_k^i + \beta_2 [(C_k/C_w) F_w^i] + \epsilon_A.$$

While the first model allows β_0 to take on any value, the second restricts β_0 to zero. The third and fourth models are presented in Table 15. These involve estimating equation [B]:

$$[B] \quad F_{xk}^i = \gamma_0 + \gamma_1 (F_k^i - (C_k/C_w) F_w^i) + \epsilon_B.$$

This is equivalent to imposing the restriction $\gamma_1 = \beta_1 = -\beta_2$. Again, the difference between the models is whether γ_0 is restricted to equal zero. The Heckscher-Ohlin-Vanek model as expressed in equation [2] predicts that $\gamma_0 = 0$ and $\gamma_1 = 1$.

The general observation about the four versions of each of these models is that while the method of depreciating capital does not affect the results appreciably (compare versions 1 and 3 to versions 2 and 4), a slight difference can be attributed to whether PPP (versions 1 and 2) or market exchange rates (versions 3 and 4) are used. However, in neither case is a significant difference generated. Overall, the results of the four models are very consistent.

Table 14 shows that the estimated coefficient β_1 is always significant at the .01 level; however, it is also always opposite in sign to that predicted by the Heckscher-Ohlin-Vanek model. While the estimated coefficient β_2 only becomes significant (at the .10 level) in two of the equations, its sign is always positive (also opposite to the prediction of the model). The constant term is never significant, and only slightly alters the estimated values of β_1 and β_2 when it appears in the equation. The F statistics are always significant at the .01 level. Overall, the results suggest that factor endowments play a significant role in determining net trade flows - however, it is not the precise role predicted by the Heckscher-Ohlin-Vanek model. This suggests a reaffirmation of the results of the "rank" test, relative to those of the sign and "strong" tests. In addition, the consistency of the signs of β_1 and β_2 throughout these equations suggests that the relationship being detected is of the form:

$$F^i_{xk} \text{ is a function of } -(F^i_k - (C_k/C_w)F^i_w).$$

Table 14. Regression Results for Equation [A] (Including E)

$$[A] \quad F_{xk}^i = \beta_0 + \beta_1 F_k^i + \beta_2 [(C_k/C_w) F_w^i] + \epsilon_A$$

(t statistics in parentheses)

	β_0	β_1	β_2	F-Statistic	R ²
(1)	33454 (1.198)	-.011259 (-2.810)***	.005936 (1.413)	10.492***	.3498
(2)	33653 (1.204)	-.011258 (-2.810)***	.005929 (1.411)	10.501***	.3500
(3)	34452 (1.249)	-.011758 (-3.056)***	.006328 (1.616)	10.943***	.3594
(4)	34653 (1.256)	-.011759 (-3.056)***	.006323 (1.615)	10.952***	.3597
(1)		-.011170 (-2.773)***	.006664 (1.594)	9.884***	.3308
(2)		-.011168 (-2.773)***	.006663 (1.594)	9.882***	.3307
(3)		-.011461 (-2.963)***	.006845 (1.746)*	10.240***	.3386
(4)		-.011459 (-2.963)***	.006843 (1.746)*	10.237***	.3386

Number of Observations: 42

Significance Levels: *** = .01 ; * = .10

Table 15 presents the results of the restricted versions of the equations in Table 14. These results also support the relationship between net trade in factor services and factor endowments specified above. The estimated coefficient γ_1 is always significant at the .05 level, and always negative - the opposite sign of that predicted by the Heckscher-Ohlin-Vanek model. Again, the constant term is never significant, and its presence rarely alters the value of γ_1 . The F statistics are always significant at the .05 level. While these results indicate the loss in predictive power from imposing the restriction specified in equation [B], they also support the general conclusions from the results in Table 14.

In order to explore the functional form further, tests were performed on the imposition of the restriction $\beta_1 = -\beta_2$ using t tests on the equations in Table 14. In the t tests, the null hypothesis that $\beta_1 = -\beta_2$ could be rejected at the .01 level. Thus, the proper form for these equations is not that specified in the Heckscher-Ohlin-Vanek equations.

As an extension to the basic regressions, it was hypothesized that there may be other variables not included in the original equations causing a lack of support for the Heckscher-Ohlin model. These other variables were introduced in the general form of dummy variables - one type considers the influence of country-specific features (as compared to the United States), while the other type considers the influence of factor-specific features (as compared to the environment). The resulting equations were examined to see first, if the original factor endowment variables now had coefficients that conformed to the Heckscher-Ohlin model, and second, what the contribution of

Table 15. Regression Results for Equation [B] (Including E)

$$[B] \quad F_{zk}^I = \gamma_0 + \gamma_1(F_k^I - (C_k/C_w)F_w^I) + \epsilon_B$$

(t statistics in parentheses)

	γ_0	γ_1	F-Statistic	R^2
(1)	-16183 (-.574)	-.010680 (-2.320)**	5.382**	.1186
(2)	-16183 (-.574)	-.010678 (-2.320)**	5.381**	.1186
(3)	-16174 (-.570)	-.009779 (-2.200)**	4.840**	.1079
(4)	-16174 (-.570)	-.009777 (-2.200)**	4.839**	.1079
(1)		-.010680 (-2.339)**	5.472**	.1177
(2)		-.010678 (-2.339)**	5.470**	.1177
(3)		-.009780 (-2.219)**	4.922**	.1072
(4)		-.009778 (-2.218)**	4.920**	.1071

Number of Observations: 42

Significance Level: ** = .05

the dummy variables was as a group. The summary results are presented in Table 16 (and the full results are available upon request).

Table 16

Effect of Introducing Dummy Variables

	No dummies	Country	Factor	Both
Coefficient signs fit theory?	NO	NO	NO	NO
$\beta_1 = -\beta_2$ restriction holds?	NO	NO	NO	NO
F statistic testing contribution of dummies - Significant?*				
Eq. [A] - w/intercept	NO	NO	NO	NO
- w/out intercept	NO	NO	NO	NO
Eq. [B] - w/intercept	YES**	NO	NO	NO
- w/out intercept	NO	NO	NO	NO

* The results were identical for all four versions of each model.

** F statistics are significant at the .05 level, but suggest that the misspecification is associated with the erroneous imposition of the restriction.

With respect to the first point, adding the dummy variables did not change the basic regression results. That is, the reason for the findings contradictory to Heckscher-Ohlin is not related to general country- or factor-specific influences. Thus, it seems that the factor endowment variables are capturing all of the effects associated with factors, and that there is some support for the use of a single A matrix given that countries as a group have no impact.

The range of values for β_1 was -.010533 (in eq. [A](1) with country dummies) to -.012704 (in eq. [A](3) with factor dummies), and for β_2 was .003049 (in eq. [A](1) with factor and country dummies) to .005996 (in eq. [A](2) with country dummies) with respect to the equations with intercepts in Table 14. The range of values for γ_1 was -.008930 (in eq. [B](3) with intercept and country, or country and

factor, dummies) to $-.010680$ (in eq. [B](1) with or without intercept and with factor dummies) with respect to the equations in Table 15. Overall, the results show a large degree of consistency among themselves and with the results in Tables 14 and 15.

Although the dummy variables as a group had no appreciable effect on the regression results, Tables 17 and 18 summarize the significance of the individual country and factor dummies found in the various models. We see that of the countries in Table 17, in general only the dummy for Japan was significant, which is consistent with Japan being the least similar to the United States; virtually every country is significant in the model with two erroneous features - the intercept and the restriction on functional form.

Of the factors in Table 18, the only significant dummy variable is that for low skill labor in the model without an intercept and without a restriction on functional form, when country dummies are not present. This suggests a possible problem related to the measurement of this labor variable.

The analysis of all of the regression results leads to the conclusion that the basic finding of the nonparametric tests is supported in the regressions. Factor endowments do play a role in influencing net trade flows, but it is the reverse of that predicted by Heckscher-Ohlin.

Table 17. Country Dummies
(comparison between indicated country and United States)

Significant?	Canada	France	W.Ger.	Italy	Japan	UK
Eq. [A]						
w/intercept	N	N	N	N	Y***/Y*	N
w/out int.	N	N	N	N	Y***	N
Eq. [B]						
w/intercept ¹						
(1) & (2)	Y**/Y*	N	Y***/Y**	Y**	Y***	Y*/N
(3) & (4)	Y**	N	Y**	Y**	Y***	Y*
w/out int.	N	N	N	N	Y*/Y**	N

¹ This is a model with two erroneous features: restricted functional form and intercept.

Significance Levels: *** = .01, ** = .05, * = .10

Unless otherwise specified, results are the same if factor dummies are also present in the equation (if different, results are presented as: country/country & factor). Also, unless otherwise specified, results are the same for all four versions of each model.

Table 18. Factor Dummies
(comparison between indicated factor and environment)

Significant?	Capital	Agr. Land	Forest Land	High Skill Labor	Low Skill Labor
Eq. [A]					
w/intercept	N	N	N	N	N
w/out int.	N	N	N	N	Y**/N
Eq. [B]					
w/intercept	N	N	N	N	N
w/out int.	N	N	N	N	N

Significance Level: ** = .05.

Unless otherwise specified, results are the same if country dummies are also present in the equation (if different, results are presented as: factor/factor & country). Also, unless otherwise specified, results are the same for all four versions of each model.

IV. IMPLICATIONS OF THE RESULTS

The empirical investigation conducted in this essay was designed to examine a number of ideas. First, this model sought to describe the role of the environment as a factor of production in determining net trade flows. In order to do this, a measure of the environment had to be developed - a proxy measure based on output of emissions was used. While this was done following McGuire (1982) from the theoretical literature, the dominant theoretical concept is environmental assimilative capacity. Until we develop the ability to measure assimilative capacity, we are forced to use proxies to capture this feature of the environment as a factor of production. The results suggest that this was a weak proxy, but it seems to be a better alternative to a qualitative measure, such as that used by Tobey (1990).

Second, the countries used for empirical analysis were chosen to represent a group similar in relative factor endowments (in 1977), so as to make the attainment of factor price equalization less unrealistic. The countries - Canada, France, West Germany, Italy, Japan, the United Kingdom, and the United States - were expected to be a group from which to find some support for the Heckscher-Ohlin-Vanek model based on similar relative factor endowments. In general, the strong results of the "rank" test suggest that a setting was established which fits the assumptions of the Heckscher-Ohlin-Vanek model. However, the results of both the "rank" and other tests suggest that the significant role played by factor endowments in determining net

trade flows among these countries was not of the form predicted by Heckscher-Ohlin-Vanek with the environment included in the data set (Cf. Appendix B).

Third, this empirical exercise was designed to demonstrate a complete test of the Heckscher-Ohlin-Vanek equations by using the information provided by all three elements - net trade flows (T), factor endowments (V), and factor intensities (A). The nonparametric tests and regression analysis are conducted on the basis of a complete test - but the results suggest that the data do not support the relationship established in the Heckscher-Ohlin-Vanek equations.

A strong, significant relationship is established between factor endowments and net trade flows, however, for this data set it is not of the form predicted by the Heckscher-Ohlin-Vanek model. This relationship is demonstrated in the significance of the coefficient in the regressions and the "rank" test results. However, all the tests based on the full equations - the sign and "strong" tests, and the regressions - provide support for the point raised in the first essay; namely, that the form of the equations is too restrictive to find strong support with real world trade flows. This in turn confirms the idea that expecting the Heckscher-Ohlin-Vanek model to be an accurate predictor using trade data generated by a variety of means (not just relative factor endowments) is unrealistic. What we are limited to evaluating are the insights the model can offer, without achieving an exact fit.

These results indicate that Heckscher-Ohlin-Vanek is only useful to the extent that it describes a role for factor endowments in determining net trade flows. The results firmly provide support for such a relationship. However, rather than excess

factor supplies generating positive net exports of a factor as predicted by Heckscher-Ohlin-Vanek - the opposite (or Leontief paradox) is true. In fact, the regression results provide strong support for the Leontief paradox in a multicountry context. In so doing, this research is consistent with the majority of the literature in finding a persistence of the paradox. However, given the dominant influence of the environment, further investigation will be necessary to draw the final conclusions from these results (see Appendix B).

The most obvious explanation for the nature of the results lies in the trade data used. These data represent actual trade flows which are influenced by a variety of elements - not the least of which is commercial policy. Even beyond the influence of other theories of trade, the fact that trade data do not come from the free-trade world of Heckscher-Ohlin is the primary impediment to their conforming to the predictions of this particular model.²⁹ However, as it would be impossible to control for these policies and create a free-trade data set, we must in general resign ourselves to poor empirical results when attempting to estimate restrictive models.

One plausible explanation for the results obtained here has its roots in interest group theory (see Olson (1965)). Most commercial policy formed in the United States and other countries is influenced by special interest groups representing the various industries affected by trade policies. The groups most effective in achieving results of direct benefit are small and organized with a common interest - such as an

²⁹ As Deardorff (1979) notes, the ability of Heckscher-Ohlin to predict the pattern of trade in goods does break down in the presence of trade impediments, whether we consider two, or more, countries. However, it is not clear whether this breakdown occurs in the Heckscher-Ohlin-Vanek model of the factor content of trade.

industry, or (of particular relevance here) ownership of a factor of production.

Therefore, since the results obtained here show net exports to be associated with scarce factors (rather than abundant), it may be because the well-organized groups of owners of these scarce factors have been able to influence commercial policy in their favor.³⁰ In this way, the Heckscher-Ohlin-Vanek prediction is completely reversed.

The general observation from these results is that this particular application of the Heckscher-Ohlin-Vanek model produced not unexpected results in failing to support the theory. It seems that some of the general objections raised in the past with respect to this model might also be applicable here. There is a suggestion, from Ramazani and Maskus (1990) among others, that the United States should not be the source of the **A** matrix because its technological requirements are such that it is an outlier compared to other countries. In an article critical of Heckscher-Ohlin theory, Elmslie and Milberg (1992), in results for 1959 and 1965, demonstrate that in correlations of vectorized **A** matrices the United States is not the outlier it has been suggested to be. Moreover, the convergence literature demonstrates technology convergence among the relatively advanced countries since 1965, implying that the United States would be even less of an outlier by 1977. In combination with an appropriate group of countries, the use of the **A** matrix from the United States should not generate error greater than that from using the **A** matrices of other countries. The role of the **A** matrix is a topic for further empirical research.

³⁰ In fact, Zandano (1969) demonstrates just such an effect in the context of the Heckscher-Ohlin model. It would be interesting to extend his work to the Heckscher-Ohlin-Vanek model.

Although this application examines only the manufacturing sectors of the economy, since net trade flows are the focus it is reasonable to expect Heckscher-Ohlin-Vanek to hold. Helpman (1981) expands the Heckscher-Ohlin model in order to describe both interindustry and intra-industry trade. Heckscher-Ohlin is still the explanation of interindustry trade; relative factor abundance is revealed in net trade flows. Intra-industry trade only influences gross trade flows. So although manufacturing sectors are the source of most intra-industry trade, the net export flows should still reveal interindustry trade patterns following Heckscher-Ohlin-Vanek.

The directions of further study indicated by this analysis are of three main types. First, researchers in general should lower their expectations for Heckscher-Ohlin-Vanek results and accept that the insights it offers in its pure form are limited. Because of the lack of empirical support, the model should probably be replaced with some other factor endowments based model. Second, there is still a need for an adequate measure of the environment variable. The proxy offered here is a reasonable first step, but performs poorly, in part because of its limited scope. Third, this empirical analysis suggests that the Heckscher-Ohlin-Vanek model may not be the best setting in which to examine the interaction between trade and the environment.

This last issue is the departure point for the third essay which extends a model of dynamic comparative advantage to incorporate the impact of pollutants over time. The model developed considers comparative advantage based on differences in technology (following the Ricardian model) rather than factor endowments, in a setting more appropriate to the nature of the environment's influence on trade flows.

SECTION 3

DYNAMIC COMPARATIVE ADVANTAGE AND THE ENVIRONMENT: AN APPLICATION OF NON-TRADITIONAL TRADE THEORY

I. INTRODUCTION

Although Heckscher-Ohlin has long been a dominant theory of international trade, since the early 1980s trade theories have arisen that specifically take issue with several of its traditional assumptions. As described in the first two essays, Heckscher-Ohlin is a relatively simple,¹ intuitively appealing theory. This achievement comes at the cost of a number of restrictive simplifying assumptions such as constant returns to scale, perfect competition, a single time period, and trade based solely on differences in factor endowments. In contrast, although necessarily less general in applicability, the newer theories are dynamic and varied; some analyze growth and technological progress, others address imperfectly competitive markets and/or increasing returns to scale, and all have a basis of trade in addition to static comparative advantage. This essay adapts a model derived from these newer theories to consider environmental pollution in a setting of dynamic comparative advantage which captures the special problem of the accumulation of pollutants over time.

In making the transition from the static to the dynamic framework, the question being analyzed also changes. In addition to the impact of the environment on trade considered in the static model, the dynamic analysis considers the impact of trade on the environment. This in turn requires that the feature which is the source of comparative advantage changes in the modeling. In the static model, since the environment is treated as a factor of production, differences in relative factor

¹ Corden (1974: 184) refers to the body of orthodox theory, in which he includes Heckscher-Ohlin theory, as "simple-minded".

endowments are the source of comparative advantage. However, since we will see that the effects of trade on the environment work through the production function, the dynamic model must use a setting in which technological differences are the source of comparative advantage. Thus, we move from the Heckscher-Ohlin model in which technologies are constant across countries to the Ricardian model in which technologies differ across countries in order to change the nature of the question being asked in the model.

As discussed in the second essay, there is a fairly substantial theoretical literature extending the static Heckscher-Ohlin model to the problem of environmental pollution. While these are important contributions, only part of the implications of pollution can be addressed in the static framework of that model. Specifically, only the pollution generated in a single period can be included. Although this type of pollution does have a serious impact, the accumulation of pollution over time is a different and possibly more serious problem. In order to capture the latter feature, the environment must be incorporated into a dynamic model of international trade. In such a model, the dynamics of the environment and trade interactions over time can be explored.

Pethig (1976), for example, notes that dynamics need to be considered, since only a model which includes the accumulation of pollutants can discuss the intertemporal aspects of environmental assimilative capacity. It is not possible in a static model to discuss the full implications of pollution exceeding some level beyond which the environment is irreparably damaged. All that can be captured in a static

model is whether the assimilative capacity has been exceeded - the implications of the economic activity that then takes place cannot adequately be addressed in a single period model. By contrast, in a dynamic model, the impacts of exceeding environmental assimilative capacity can include incentives to engage in pollution abatement activities.

The mechanism of change in the models of dynamic comparative advantage that have been developed to date is related to the notion that comparative advantage is something that can be created over time through learning, which may involve investment in human capital or investment in research and development. Important work in dynamic comparative advantage includes Krugman (1987), who incorporates the dynamics of an industry learning curve, and Grossman and Helpman (1989, 1991), whose dynamics are associated with the product innovation process.

There are two possible ways to incorporate a treatment of pollution into the dynamic comparative advantage approach. In the first, pollution impacts on the productivity of inputs, as Merrifield (1988) presents in a static setting. The second models investment in environmental controls or assimilative capacity in the same way that investment in research and development has been modeled. In this interpretation, pollution generation can be thought of as negative technological progress (as in McGuire (1982)).

In this essay, a model will be constructed in which the *stock* of accumulated pollutants plays a separate role from the *flow* of pollutants created at a single point in time. This model is suggestive of some of the outcomes that are likely to result from

this type of analysis, however it is still preliminary. This essay represents a report on a work in progress. Future research will be devoted to deriving the full implications and extensions of the model sketched here. For example, in a dynamic model, a clearer argument may be made for the development of pollution control industries that serve to maintain a country's competitive position internationally, and mitigate the transfer of pollution to foreign countries. The possibility of reaching the environmental assimilative capacity is the motivation for creating control industries in a dynamic model; in a static setting, if pollution abatement industries exist they are an exogenous feature related to environmental conditions in some previous time period.

A. Static vs. Dynamic Pollution Concepts

In the static framework I demonstrated that the environment is used in the production process - in the sense that pollution is generated from the production activity that takes place in a single period. In the static framework, we consider only the impact of pollution flows in each period - that is, we examine the question "what is the effect of new pollution on the system?" While this impact is important, it fails to reveal another important feature of most types of pollution. The flows of new pollution create a stock of accumulating pollution, and this accumulating pollution also has an impact on the production process.

Stocks of accumulated pollutants do not necessarily continuously increase because certain types of pollutants will dissipate through time, but it is true that in most cases the original pristine condition of the environment before pollution cannot

be reproduced. In a dynamic context we can discover the implications of the existence of, and changes in, the stock of accumulated pollutants.

There are two ways in which to think about the stock of pollution. One is as a factor of production - similar to the static case - whose quantity changes through time. The other is as a factor which alters the quality - i.e., productivity - of other factors of production through time. For instance, pollution may increase the deterioration of the capital stock, increase the likelihood of illness or death in the labor force, or reduce the productivity of land.

In the first case, pollution is similar to negative technological progress because output tends to diminish over time as pollution increases. In the second case, the interactions between pollution and the other factors of production have the opposite effect of interactions between research and development and other factors. These interactions tend to reduce the rate of increase in output over time; thus, this case is also similar to negative technological progress.

In a dynamic framework it would also be possible to consider research and development and pollution in the same model. In such a model, one can investigate the impacts of investment in research and development in pollution abatement technology on reducing the amount of pollution and on creating a comparative advantage in the pollution abatement industry in a country that heavily uses its environment. In this type of model we can see how the existence of the stock of accumulated pollutants creates a new industry. Such a possibility does not arise in a static model.

The question asked in the dynamic technology-based (Ricardian) comparative advantage framework is different from that in the static endowments-based (Heckscher-Ohlin) comparative advantage framework. Rather than "does the environment play a role in determining net trade flows?", it is "how does the environment influence the character of international trade through its interactions with other factors of production and what are the feedback effects of trade on the environment?" Rather than the static comparative advantage of an environment-abundant country, it is the dynamic comparative advantage of a country - or industry - affected by the quality of the environment.

B. Static vs. Dynamic Comparative Advantage

The first model to be discussed in this essay - Asako (1979) - is an example of a model that considers the dynamic nature of pollution in a static comparative advantage framework. Comparative advantage exists prior to trade, in this case as a function of technology (a Ricardian model). The model demonstrates how changes in environmental quality cause trade patterns to alter from the patterns dictated by comparative advantage.

Asako's is not the approach followed in the dynamic comparative advantage models; in these models comparative advantage is generated through the process of engaging in trade. While dynamic comparative advantage is the approach that is followed in the construction of the model in this essay, Asako is presented for contrast, and to introduce the idea of technology-based comparative advantage.

Models of dynamic comparative advantage allow the environment to play a more fundamental role in determining the character of trade. Changes in environmental quality/quantity direct trade rather than work against some other source of comparative advantage. In addition, this type of model addresses the impact of trade on the environment. The goal of this essay is to develop a model that contains both a dynamic conception of the environment and dynamic comparative advantage. The interest in developing this model is to analyze changes in the environment and trading systems over time. This essay represents the outline of a research program that will continue to develop the implications of this model.

II. A MODEL OF POLLUTION ACCUMULATION

Most of the trade models incorporating the static impacts of environmental pollution were discussed in the second essay. These models generated trade patterns in which countries relatively well-endowed with environmental quality specialize in the export of environment-intensive goods. Countries gain from trade when specializing according to their comparative advantage in factors of production. In contrast to these models, Asako (1979) considers the dynamic implications of pollution, although comparative advantage remains a static concept. Asako begins with a static Ricardian model, with technology-based comparative advantage, and develops a model that demonstrates that a country with a comparative advantage in a pollution-intensive commodity may suffer a welfare loss when it opens to international trade. This result is possible because the model considers the utility of consumers along with productivity advantages.

In Asako's model, production (y) involves a single factor, labor (L), which is completely used in producing two commodities. The technology in both industries is subject to diminishing returns. Thus,

$$y_i = f_i(L_i) \quad f_i' > 0, f_i'' < 0 \quad \text{and} \quad L = L_1 + L_2.$$

where i represents the industry (commodity) ($i = 1, 2$), and labor is fully employed.

A flow of pollutants (p) is generated as a by-product of the production process in each industry according to functions subject to increasing returns

$$p = g_1(y_1) + g_2(y_2) \quad g_i' > 0, g_i'' > 0.$$

The amount of pollution generated increases as output increases, and the effects of pollution do not cross national borders.

Utility is a positive function of the consumption (c) of the two commodities, and a negative function of pollution, with diminishing marginal utility and (for simplicity) zero cross derivatives, or

$$U = U(c_1, c_2, p), \text{ where } U_i > 0, U_p < 0,$$

$$U_{ii} < 0, U_{pp} < 0; U_{ij} = 0 \text{ for } i \neq j \quad (i, j = 1, 2, p).$$

Goods market equilibrium requires that consumption is the difference between production and net² exports (b) of each commodity: $c_i = y_i - b_i$. Trade balance equilibrium requires that net exports (imports) of the first commodity are offset by net imports (exports) of the second commodity, after adjustment for the terms of trade (π) expressed as the relative price of the second good with respect to the first (p_2/p_1). Thus, we have $b_1 + \pi b_2 = 0$.

The marginal conditions $f_1'/f_2' = \pi = U_2/U_1$ follow from this model, that is, production and consumption decisions are made on the basis of equating marginal productivities and marginal utilities for given relative costs (π). Therefore, the change in welfare generated by a change in the terms of trade is:

$$\frac{dU}{d\pi} = U_1 b_2 - \frac{U_p f_2' (g_2' f_2' - g_1' f_1')}{(f_1'' + \pi f_2'')}$$

² This is an unfortunate choice of terms on Asako's part. A Ricardian trade model with equal-sized countries assumes that complete specialization will result, so that each country will produce and export one good (and import the other). Since the commodities are homogeneous between countries, the use of the term "net" is inappropriate. If, however, the countries are of different sizes, incomplete specialization is possible and prices will adjust to ensure that trade takes place according to Ricardian comparative advantage.

This is obtained by substituting the production function information into the marginal conditions, and using the equilibrium conditions in combination with the marginal conditions, in order to make substitutions into the utility function which is then totally differentiated.

For a small departure from autarky (i.e., no trade) for a country that specializes in commodity 2, b_2 can be set equal to zero. Therefore, in order to sign $dU/d\pi$, we need to determine the sign of the second term. From the original assumptions, U_p is negative and $[-f_2'/(f_1'' + \pi f_2'')] is positive, so the ambiguous sign is associated with $(g_2'f_2' - g_1'f_1')$ and depends on which sector is relatively more pollution intensive.$

For example, if the industry producing good 2 is more pollution intensive, then $(g_2'f_2' - g_1'f_1')$ is positive, and therefore, through the second term, $dU/d\pi$ is negative. Thus, an increase in π - the result of exporting commodity 2 in return for commodity 1 - decreases welfare. This leads Asako to the proposition that in this situation if a country opens to trade by exporting a more pollution-intensive commodity and importing a less intensive one, the welfare of the country decreases.

The result obtained here is generated by the structure of preferences and Ricardian comparative advantage, and hinges on the size of the usual gain from trade (U_1b_2) and the extent to which this gain could offset the negative impact of increased pollution. In this model, the external costs of pollution are not considered at all by firms. Asako's result offers an argument for restrictive trade policies which act as environmental policies to reduce pollution, although as Asako notes, this would be a

second-best policy option. The first-best policy for a domestic pollution problem is a domestic tax or subsidy program.

In the dynamic analysis, Asako addresses the issue of the accumulation of pollutants by modifying one part of the static model. Here, pollution is treated as a stock variable whose quantity changes over time and the only feature changed from the static model is the specification of the pollution equation.

Pollution accumulation - the change in the stock of pollution (P) per unit time - is represented by the flow of new pollutants less the decay in the stock of pollutants. The existing stock of pollution is assumed to dissipate according to a constant decay rate (ν). Thus, since $\dot{P} = g_1(y_1) + g_2(y_2)$, pollution accumulation is given by:

$$\frac{dP}{dt} = g_1(y_1) + g_2(y_2) - \nu P.$$

Asako assumes a small country with fixed terms of trade and solves the social planner's problem to find the dynamic optimal trade policy. This involves maximizing the discounted sum of the stream of future utilities

$$\int_0^{\infty} U(c_1, c_2, P) e^{-\delta t} dt$$

subject to the specifications of the model and some given initial level of pollution.

Asako considers the path to the stationary state which depends on whether the initial environmental quality is higher or lower than that achieved in the stationary state.

For example, if we begin from a higher level of environmental quality,³ pollution accumulates over time, deteriorating environmental quality, until it reaches the level of the stationary state. Asako finds the typical optimal result that as pollution worsens its social cost should be made higher, which means that production should be shifted from the more pollution-intensive sector to the less intensive sector over time. The structure of preferences dictates that consumption of both goods decreases as pollution accumulates. The outcome is an adjustment in the trade pattern, with net exports of the pollution-intensive commodity decreasing and net exports of the less intensive commodity increasing. The result of the dynamic analysis is that,

when a country has a comparative advantage (or disadvantage) in the pollution-intensive commodity so that it exports (or imports) that commodity, international trade activities should be curtailed (or promoted) over time as pollution accumulates. This enables the country to transfer indirectly pollution to foreign countries. (Asako 1979: 362)

The transfer of pollution occurs because environmental degradation decreases welfare. Since this comparative advantage model is Ricardian, it is possible that a country will not face a welfare gain from opening to trade. In the Heckscher-Ohlin model, by contrast, countries are always made better off by engaging in trade. This transfer also results because the only way to reduce pollution is to reduce production of the environment-intensive commodity - the option of pollution abatement does not exist in this model. Asako (1979: 365) remarks, "the comparison of the role of

³ The entire story is reversed if beginning from a lower level of environmental quality than in the stationary state.

pollution abatement investment with that of controlling the international trade activity is of much interest since to some degree they are alternatives." We have already recognized that alternative policies - either trade or environmental - may be used to control pollution; note that requiring pollution abatement activities would be a domestic policy option. If we incorporate Asako's analysis into that of the dynamic comparative advantage models, it is possible that the use of different policies will also cause changes in trade patterns.

In addition to the limitations just discussed, a model such as Asako's also does not allow for the possibility that polluting industries may stay in their original location and invest in the development of abatement technologies rather than move - directly or indirectly - to foreign countries. The option of maintaining the industry not only generates an advantage in pollution abatement in the original location, but may also generate a higher degree of innovation in the polluting industry. Both features serve to create a comparative advantage where one had not existed on a purely endowments basis.

III. A MODEL OF DYNAMIC COMPARATIVE ADVANTAGE

In this section, I examine Krugman's (1987) model of dynamic comparative advantage, in which the dynamics enter through an industry learning curve and the effect of cumulative experience. Models of dynamic comparative advantage are designed to address the evolution of trade patterns over time. The framework of Krugman's model is adapted in the last part of this essay to include a dynamic treatment of pollution in order to discuss the interactions between two evolving systems - trade patterns and pollution accumulation.

Krugman (1987) develops a very simple model of international specialization that highlights the role of the learning curve at the national level. In this model, the learning curve is the source of dynamic economies of scale as cumulative past output determines current productivity. While the model is acknowledged to be simplistic and to generate extreme results, its purpose is to emphasize possibilities missed by conventional theory. Krugman's model of dynamic comparative advantage is constructed explicitly as a model of trade between two countries.

In this model, knowledge (experience) is generated in the production process. Each country initially specializes in certain industries according to comparative productivity advantages when they open to trade. The impact of the learning curve is felt by the labor force in a particular industry which becomes more skilled (productive) and thereby able to produce more output. As time goes on, greater levels of production generate further knowledge and a more productive labor force in

that industry. This process continues indefinitely as countries become highly productive in the industries in which they are specialized because experience enhances comparative advantage and specialization.

Thus, by incorporating a growth of knowledge function, comparative advantage is enhanced over time. The productivity advantages that result from the learning curve in a particular industry become a barrier to entry that increases in severity over time. Through the analysis of the dynamic implications of learning for specialization one can develop an explanation for the persistence of comparative advantage for countries in particular industries, whatever the reason these countries originally specialized as they did.

This model raises the question of the impact of a mechanism that would act to decrease productivity. That is, if continually increasing productivity enhances comparative advantage, does continually decreasing productivity diminish it? This is the question to be addressed in the next section of this essay. First I discuss the details of Krugman's model.

In this model there are two countries, Home (denoted by capital letters) and Foreign (denoted by lower-case letters), each of which has a single factor of production - labor. Labor is used in the production of n traded goods and one nontraded good. The model is Ricardian at a point in time because comparative advantage is associated with the technology - specifically, labor productivity - used to generate output.

At a point in time, there are constant returns to the production of each traded good

$$(a) \quad X_i(t) = A_i(t)L_i(t) \quad x_i(t) = a_i(t)l_i(t) \quad i = 1, \dots, n$$

where X_i is the output of traded good i , L_i is the labor devoted to the production of traded good i , and A_i is the inverse unit labor requirement (a measure of labor productivity).

Over time, however, there are dynamic increasing returns in the form of an industry learning curve. In each industry in each country, labor productivity depends only on an index of cumulative experience (K)

$$(b) \quad A_i(t) = K_i(t)^\epsilon \quad a_i = k_i(t)^\epsilon \quad 0 < \epsilon < 1$$

where labor productivity is enhanced as labor becomes more experienced (skilled) over time in the production process. Krugman assumes that the learning curve is associated with the industry but external to firms so that perfect competition prevails among firms.

Learning is a function of accumulated output, and the index of experience depends on both domestic and foreign production. This model allows for the international diffusion of knowledge; knowledge spillovers are not confined to national borders. Thus, the index of experience is specified as

$$(c) \quad K_i(t) = \int_{-\infty}^t [X_i(z) + \delta x_i(z)] dz$$

$$k_i(t) = \int_{-\infty}^t [\delta X_i(z) + x_i(z)] dz \quad 0 \leq \delta \leq 1$$

where δ is a measure of the international transmission of knowledge. The value of δ is assumed to lie between 0 (at which point all learning is national) and 1 (at which point knowledge flows as readily internationally as nationally) for most industries. Equation (c) shows that the total knowledge available at time t is a function of the total output accumulated to time t .

Krugman's specification of the index of experience presents a problem for the typical Ricardian model. In such a model with two countries of equal size, opening to trade results in complete specialization. With trade the countries only produce the goods in which they specialize according to their technological comparative advantage. These goods will be their exports, and all other goods will be imported.

The implication of this for equation (c) is that once the countries open to trade, knowledge is a function of domestic production only; foreign production will not take place in the domestic country's comparative advantage industries. It appears, however, that the general conclusions of Krugman's model are not substantively impacted if there is no international transmission of knowledge. The dynamics of the model do not depend on knowledge spillovers across borders.

To complete the specification of the model, Krugman assumes full employment and exogenously given total labor forces at any point in time ($L(t)$ and $l(t)$). Both labor forces are assumed to grow exponentially at rate g . Expenditure is assumed to be equal to income. A constant income share $1 - s$ is assumed to be spent on the nontraded good, while a constant and equal share s/n is spent on each traded good.

The analysis of the dynamics of the model is divided into two main parts. The first part of analyzing international specialization involves the determination of relative productivities over time, given fixed resources. This first part of the analysis involves holding the relative labor force allocation constant, in which case the system converges on a steady-state value of relative experience. Given that the ratio of the knowledge functions is stable, the ratio of labor productivities is also stable, even though each country's particular value of experience or labor productivity may be changing. This first part describes medium-term dynamics.

The second part of the analysis of the dynamics considers changes in the relative labor allocation with fixed relative productivities. This exercise generates the short-run specialization pattern for particular allocations of resources; the fixed relative productivities determine which goods will be produced and exported by each country.

The complete analysis of the dynamics puts these two parts together, allowing both relative labor forces and relative labor productivities to change. The full long-run situation includes labor forces growing exponentially, and a ratio of indices of experience that is not required to be stable. The latter of these induces changes in relative productivities over time.

With every feature allowed to change, the ultimate result of the model is that each country becomes more productive in the industries in which it is specialized as it progresses further along the industry learning curve. Continued production in a particular industry increases the knowledge (experience) level in that industry so the

labor force becomes more productive, increasing production, and therefore knowledge, even further. As production according to specialization continues, the countries are driven to the limit of productivity in their particular industries. The learning curve enhances the pattern of specialization, and is the source of dynamic increasing returns.

Thus, Krugman proceeds to analyze international specialization in three steps. The entire analysis is conducted from the perspective of the autarky (no-trade) situation. Because of the complete specialization that results with trade, our ability to rank industries in terms of relative productivities and to discuss the dynamics of comparative advantage both rest on relationships established prior to the onset of trade.

First, we determine relative productivities over time. This becomes the analysis of the path to the steady state because the relative labor allocation is held constant. Since relative productivity is a function of the relative indices of experience, from (b) we have

$$(d) \quad \frac{A_i(t)}{a_i(t)} = \left[\frac{K_i(t)}{k_i(t)} \right]^e$$

As Home's relative experience in a particular industry increases, so does its relative productivity. Labor productivity improves as the knowledge about production in an industry contributes to labor's efficiency. Therefore, the dynamics of relative productivity come from the indices of experience, and from (c) we have

$$(e) \quad \frac{dK_i(t)}{dt} = X_i(t) + \delta x_i(t)$$

$$\frac{dk_i(t)}{dt} = x_i(t) + \delta X_i(t)$$

The additional knowledge gained in any one time period is a function of the output produced in that period. The relative percentage change in the indices of experience is therefore given by

$$(f) \quad \frac{dK_i(t)/dt}{K_i(t)} - \frac{dk_i(t)/dt}{k_i(t)} = \frac{X_i(t) + \delta x_i(t)}{K_i(t)} - \frac{x_i(t) + \delta X_i(t)}{k_i(t)}$$

If the relative labor allocation $L_i(t)/l_i(t)$ is held fixed, $K_i(t)/k_i(t)$ will converge on a steady state (where the relative (percentage) change in the experience indices is equal to zero). Examining the steady state allows us to isolate the relationship between knowledge and relative productivity. If we set the left-hand side of (f) equal to zero and substitute from (a) and (b) for $X_i(t)$, $x_i(t)$, $A_i(t)$, and $a_i(t)$ we find that

$$(g) \quad \left(\frac{K_i}{k_i} \right)^{\epsilon-1} = \frac{l_i}{L_i} \left[\frac{1 - \delta k_i/K_i}{1 - \delta K_i/k_i} \right]$$

The fixed value of L_i/l_i yields a stable value of K_i/k_i . Given the specification of international spillovers of knowledge, the steady-state value of K_i/k_i always lies between δ and $1/\delta$, however, the precise value depends on the allocation of labor. An increase in L_i/l_i leads to a higher steady-state relative K_i , because a larger labor force for Home means more output is produced by Home and therefore more progress is made along Home's learning curve.

We have now determined the steady-state value of the relative indices of experience. Since the relative indices of experience determine relative productivity, steady-state relative productivity A_i/a_i can be written as a function of the relative sizes

of the labor forces $\frac{A_i}{a_i} = \alpha\left(\frac{L_i}{l_i}\right)$ where, according to Krugman, $\alpha(\cdot)$ is implicitly

defined by (g). The function $\alpha(\cdot)$ is increasing in L_i/l_i ; the extreme values are $\alpha(0) = \delta$ and $\alpha(\infty) = 1/\delta$. Given that the value of L_i/l_i is held fixed in the steady state, the value of A_i/a_i is also stable. The steady state yields stable relative productivities, relative labor allocations, and relative indices of experience. Individual values may change, but the ratios are constant in the steady state.

Krugman leaves the steady-state analysis at this point without making any further use of it. In the next section, I omit the steady-state analysis in my adaptation of Krugman's model. I begin with Krugman's second part of the analysis discussed next.

The second step in analyzing the dynamics of international specialization is to determine the allocation of labor, holding relative productivities fixed. At a point in time, the model is Ricardian; therefore, comparative advantage is determined by technological differences between the two countries in the various industries. Thus, industries producing tradable goods can be ranked by their relative productivities $A_i(t)/a_i(t)$. The marginal industry (which produces the nontradable good) is required to meet the condition that its relative productivity is just equal to the relative wage rate that will prevail in all industries

$$(h) \quad \frac{A_i(t)}{a_i(t)} = \frac{W(t)}{w(t)}$$

where $W(t)$ is the wage rate in the marginal industry at time t . The marginal industry is the one in which neither country has a comparative advantage. Home is an

exporter of goods that satisfy $\frac{A_i(t)}{a_i(t)} > \frac{W(t)}{w(t)}$, and an importer if $\frac{A_i(t)}{a_i(t)} < \frac{W(t)}{w(t)}$; the

opposite is true for Foreign. That is, each country exports the goods of industries in which its relative productivity exceeds the marginal wage rate because these are the goods that can be produced relatively cheaply by a country, owing to its comparative advantage in the industry.

There are wage rates $W_i(t)/w_i(t)$ that in autarky pertain to each traded good industry, but with trade, wage rates equalize across industries and the overall ranking is established with respect to this wage rate of the marginal industry $W(t)/w(t)$.

Wage rates will equalize across industries because with labor mobile between industries an equilibrium with production in all industries can only be attained when the returns to labor are the same in every industry. Engaging in trade makes this equalization possible as labor is reallocated according to comparative advantage.

Since equation (h) holds for the marginal industry, the comparison boils down to one of the relative productivity in each traded good industry vis-a-vis the relative productivity in the marginal industry.

We denote as $\sigma(t)$ the share of the world tradable industries located in Home, that is, the number of tradable goods in which Home has a comparative advantage relative to the total number of tradable goods (n), for any wage-labor force combination. Once a particular equilibrium relative wage is determined, Home's

share is denoted as $\bar{\sigma}(t)$. As $\sigma(t)$ increases, $W(t)/w(t)$ declines because the relative productivity in the marginal industry has a lower and lower rank. Industries are ranked in order of highest to lowest relative productivity compared to the marginal industry (in each country). As the share of industries for Home increases, the rank (and thereby relative wage rate) of the marginal industry decreases. Equation (h) is one equilibrium condition for the allocation of labor.

The other equilibrium condition is the balance of payments (trade) equilibrium which allows us to identify the marginal industry and corresponding shares of goods produced by Home and by Foreign (by putting the demand side together with the supply side given in equation (h)).⁴ Given that expenditure is equal to income, equilibrium in the market for goods produced by Home requires that Home's labor income ($w(t)\bar{L}(t)$) equals world (Home plus Foreign) spending on goods produced by Home. Thus,

$$W(t)\bar{L}(t) = \sigma(W(t)\bar{L}(t) + w(t)\bar{l}(t))$$

where $\bar{L}(t)$ is the exogenously fixed size of the overall labor force. This condition can be rewritten as:

$$(1 - \sigma)W(t)\bar{L}(t) = \sigma w(t)\bar{l}(t)$$

This gives the trade balance equilibrium which states that imports are equal in value to exports (with respect to Home, the left-hand side is imports and the right-hand side

⁴ This analysis is derived from Dornbusch, Fischer, and Samuelson (1977).

is exports). By rearranging, we can write the trade balance equilibrium condition that determines $W(t)/w(t)$ (with equation (h)) as

$$(i) \quad \frac{W(t)}{w(t)} = \frac{\sigma}{1 - \sigma} * \frac{\bar{l}(t)}{\bar{L}(t)}$$

Equation (i) states that as Home's share of world production increases, a higher relative wage is required to maintain stability. Since an increase in Home's production increases Home's exports and decreases Home's imports, Home's relative wage must rise to increase Home's import demand and reduce Home's exports, and thereby restore balance. Equation (i) can also be interpreted as showing the relative wage at which Home's demand for labor (goods) is just equal to Home's supply of labor (goods). This is only true for the marginal industry; in all others trade accounts for the imbalances.

Finally, the dynamics of international specialization over time can be described by putting together these two parts of the discussion of the dynamics. In the absence of any exogenous shocks to the system, once a pattern of specialization is established, it remains the same; changes in relative productivity further lock-in the pattern of specialization. As Krugman (1987: 47) illustrates, "[l]ike a river that digs its own bed deeper, a pattern of specialization, once established, will induce relative productivity changes that strengthen the forces preserving that pattern." As long as there are some tradable goods produced in each country, productivity rises faster in Home for the goods produced there, while productivity rises faster in Foreign for the goods it produces. This is because accumulated past domestic output adds more to knowledge in domestic industries than accumulated past foreign output (due to the

factor δ and the fact that with trade foreign output is equal to zero in the domestic country's industries).

Thus, for Home $A_i(t)/a_i(t)$ continually increases as output increases in each industry, so the difference between the lowest value of $A_i(t)/a_i(t)$ for Home and the value of $W(t)/w(t)$ continually widens. The same is true for Foreign, leading the relative productivities in all industries present in each of the two countries to move further and further apart. As specialization continues according to comparative advantage, increased production leads to further progress along the learning curve, which in turn leads to higher relative productivity and greater comparative advantages as time progresses.

In addition, this process operates for a range of possible steady states that depend on Home's initial market share $\bar{\sigma}$ (whatever $\bar{\sigma}$ and $W(t)/w(t)$ Home starts with will be maintained over time). Thus, this is a model in which the initial conditions are critical, as they ultimately influence the final outcome. The range of possible starting σ 's is defined by the relative wage rates at which a country is competitive in an industry even if it relies solely on internationally-transmitted knowledge.

Krugman presents a model in which comparative advantage is generated over time through the process of acquiring knowledge, rather than being solely based on relative factor endowments (or some other static national feature). This model demonstrates that comparative advantage can be generated over time, as well as being connected to some static feature of a country. The idea of dynamic comparative

advantage is that the trading pattern can be altered over time by deliberate (or accidental) forces. The reason such a model is appropriate for the discussion of environmental issues is because the effect of the accumulation of pollutants is to change circumstances (such as trading patterns) over time. In addition, this type of model can show the impact of evolving trade patterns on the environment. In this type of model, one could introduce the environment in a form similar to the index of experience, as will be presented in the next section of this essay.

The weakness of the Asako (1979) model presented in the previous section of this essay is that it ignores the fact that accumulating pollutants can alter a country's comparative advantage in particular industries because the costs of pollution are not internalized. Asako's model characterizes commodities as more or less pollution-intensive and argues for a decline in exports if a country's comparative advantage is in the more pollution-intensive commodity.

On the other hand, although Krugman's model is not without its faults, it does present a useful framework for analyzing the dynamic interactions between pollution and trade. The knowledge function, which acts to enhance comparative advantage by increasing the productivity of labor, is readily adaptable to the problem of pollution. One of the effects of pollution is to worsen the health of individuals. If individuals involved in production are ill or become ill more often, they will be less productive. Thus, pollution can be conceptualized as a factor that diminishes the productivity of labor, having the opposite effect of knowledge.

In addition, just as knowledge is a function of past and current output, with continued production adding to the stock of knowledge, pollution is also a function of prior and current output, and continued production also adds to the stock of pollution. Thus, this part of Krugman's model can be adapted in a straightforward manner for a model concerned with pollution. As has been discussed, the dynamic comparative advantage framework is also appropriate to the issue of pollution and trade because of the changing and persistent nature of pollution impacts.

Krugman (1987) is used as a framework for the model developed in the next section of this essay because it has features that can be readily interpreted in terms of the issue of pollution and trade over time. Although some problems may persist, it will serve as an important first step in the theoretical development of the dynamic issues of environmental quality in international trade.

IV. A MODEL OF DYNAMIC COMPARATIVE ADVANTAGE AND POLLUTION

The model developed in this section is designed to examine the implications for comparative advantage of pollution accumulation over time. It follows Krugman (1987) in its basic structure (and notation) and employs an adaptation of the knowledge function used by Krugman to express the accumulation of pollution over time. This model examines the problem of pollution over time in a dynamic comparative advantage framework, and establishes a result that differs dramatically from that found in the literature using static models of trade.

The goal of this examination is to express the fundamentals of the relationship between pollution and trade over time. The model used is simple, perhaps overly so, but it is merely trying to capture the most basic elements of the relationship. Future research will be designed to develop the full implications of this preliminary model.

Fundamentally, international trade serves to establish a setting in which comparative advantage can exist because a country is a unit that may be associated with particular features. Once comparative advantage exists, whether it is an unexplained exogenous factor related to the inherent features of a country - such as technology or endowments - or generated endogenously through the process of engaging in trade over time, it acts to direct the production that will take place in a particular country and the pattern of trade between countries.

Fundamentally, the pollution that is generated in the course of production accumulates over time; the amount of pollution that exists at a point in time is a

function of accumulated output. As the production of output increases, the pollution generated also increases. Engaging in international trade is one motivation for increasing output, particularly in those sectors in which a country has a comparative advantage.

After developing a model that appropriately addresses the fundamentals of a relationship, one can go on to introduce such things as mitigating factors into the analysis. In the present setting, the most obvious mitigating factor would be pollution abatement activity or pollution dissipation. But this essay will focus on the development of a model of the fundamentals of pollution and trade.

The major obstacle faced in the attempt to use a dynamic comparative advantage framework is that the mechanism of growth in this type of model works through the labor forces in the various countries. This means that since the model developed here incorporates pollution as opposed to knowledge creation, it is not a model of growth as such - but rather of change over time.⁵ In addition, the mechanism of change in this model must involve a relationship between pollution and labor; while this is not a problem per se, it does limit the types of environmental impacts possible. Thus, such a model ignores environmental impacts on the capital stock, land quality, etc.

The model developed here assumes that the labor force in each country begins with some exogenously given level of productivity, which means that the countries' comparative advantages lie in the technologies used in the various industries. The

⁵ Although this is somewhat mitigated by the possibility of labor force growth (see below).

dynamics of pollution act to diminish this productivity over time. In particular, the dynamics of the model assume that with trade the environment's assimilative capacity has been exceeded in each country so that pollution only increases (there are no mitigating factors) and pollution always adversely affects the labor force.⁶ Pollution is generated in the production process, and may be the result of foreign, as well as domestic, production. Industries are assumed to be equally pollution intensive; differences in pollution levels between countries therefore arise from output differences that are generated by productivity or labor force size differentials.

In order to discuss the dynamics of the model we must consider the autarky situation - that is, the situation that exists prior to trade. The task of analyzing dynamics begins by focusing on relative labor forces (resources) and establishing the ranking of industries in terms of relative productivities. Different labor force allocations will generate different rankings of industries and different comparative advantage goods for each country. Then we consider the impact of trade taking place according to comparative advantage over time.

The ultimate result of the model is a cessation of trade; all goods become nontraded because as pollution accumulates productivities diminish and eventually comparative advantage is destroyed in every industry in which it originally existed for each country. Diminished comparative advantage is an important new result of this model. This final autarky (no-trade) state is probably not the same as the original

⁶ In order to describe the model, we also allow assimilative capacity to be exceeded prior to trade; in other words, the onset of trade and exceeding assimilative capacity *are not* required to be coincident.

autarky state because real wages and output are likely to be lower because of diminished productivity.

Thus, this model demonstrates that if two countries with polluting industries open to trade, both are worse off (unless mitigating circumstances exist). The two countries are worse off than if they had remained closed to trade because trade increases output overall, and because specializing according to comparative advantage increases output in particular industries in each country. Reinforcing increases in output contribute to further increases in pollution and diminishing productivity.

A. Specification of the Model

There are two countries in the model: Home and Foreign (Home is indicated by capital letters, Foreign by lower case). Each country uses a single factor of production, labor (L_i), to initially produce n traded goods and one nontraded good. At a point in time, there are constant returns to the production of each traded good

$$[1] \quad X_i(t) = A_i(t)L_i(t) \quad x_i(t) = a_i(t)l_i(t) \quad i = 1, \dots, n$$

where X_i is the output of traded good i , A_i is the measure of labor productivity (output per worker) for good i , and L_i is the labor used to produce good i .

Over time there are decreasing returns due to the generation of pollution. It is assumed that with trade the environmental assimilative capacity is exceeded in each country, so that all pollution has an adverse impact on productivity. However, it is also possible that assimilative capacity is exceeded before trade begins. In fact, we must allow for this so that prior to the onset of trade we can evaluate the future

impacts of pollution. The system starts from an exogenously given level of labor productivity; the initial productivity level (A_{i*}) is an inherent feature of the technology existing in each country.⁷ Thus, the specification for labor productivity is

$$[2] \quad A_i(t) = \frac{A_{i*}}{P_i(t)^\beta} \quad a_i(t) = \frac{a_{i*}}{p_i(t)^\beta} \quad \beta > 1$$

where $P_i(t)$ is the pollution function. This specification implies that labor productivity cannot be enhanced and is continually diminished by pollution which increases over time. In this specification, the pollution function is nonlinear and the initial effects of pollution are more severe than later ones. Productivity diminishes because of pollution's detrimental impact on worker's health; workers who are more ill and/or ill more often are not as productive (however, we do not require that workers ever die). With no abatement or dissipation possible, if pollution is produced as a matter of course with output, productivity will be driven close to zero and production will also approach zero. The pollution function is a feature external to firms, which are assumed to be perfectly competitive.

The structure of the pollution function is specified similar to that for knowledge in Krugman's model. We can think of the pollution in a particular country as being a function not only of domestic output, but also of foreign. Thus, the model is specified such that pollutants may be transmitted internationally as well as nationally.

⁷ This model is typically Ricardian in character, with comparative advantage being associated with technology and exogenously determined. In a Ricardian model, the "something" that makes technologies differ can be unexplained.

In addition, pollution at time t is the result of all production that has taken place from time t_0 to time t .⁸ This yields

$$[3] \quad P_i(t) = \int_{t_0}^t [X_i(z) + \gamma x_i(z)] dz$$

$$p_i(t) = \int_{t_0}^t [\gamma X_i(z) + x_i(z)] dz \quad 0 \leq \gamma < 1$$

where γ is a measure of the international diffusion of pollution. If $\gamma = 0$, pollutants cannot move internationally; such is the case with localized pollution problems in lakes or landfills. Alternatively, if γ approaches 1, pollution in one country is contributed to nearly as readily by foreign production as by domestic; this is roughly equivalent to the acid rain problem between the United States and Canada. Although most typical cases involve a value of γ somewhere between the two extremes, the case of γ close to 1 is not unusual. A number of polluting industries have a tendency to concentrate geographically, with more concern for topography (or other features) than national boundaries. If these concentrations happen to occur at a border, it is likely that γ is almost equal to 1.

There is one troubling element to this specification that is a carryover from Krugman's model. In a Ricardian model, when countries open to trade complete

⁸ The point in time t_0 indicates when the pollution function begins to diminish exogenous labor productivity (A_{ip}), that is, when assimilative capacity is exceeded. Prior to t_0 , the pollution function is normalized to 1 so that $A_i(t) = A_{ip}$. Time t_0 does not signal the onset of trade; it is possible that assimilative capacity is exceeded prior to trade.

specialization occurs.⁹ That is, if a country has a comparative advantage in an industry, when it opens to trade it becomes the sole producer (and exporter) in that industry. Thus, once the two countries begin trading with each other, pollution in each industry as specified in equation [3] is a function only of domestic production and the value of γ does not play a role because foreign production is equal to zero.

The implication of this fact for the description of the model that follows is that if pollution is a function only of domestic production, γ no longer serves as a limiting value for the various functions (see figure 3). However, the nature of the relationships described below remains fundamentally intact. Since the discussion of the dynamics assumes an autarkic situation, the model examined retains equation [3] as specified above.

To complete the specification, full employment is assumed. Each country has an exogenously given total labor force at a point in time, $L(t)$ and $I(t)$, which is assumed to grow exponentially at some rate g ($g \geq 0$). Expenditure is assumed to be equal to income. For trade balance equilibrium it is assumed that equal shares are spent on each traded good, and equal shares are spent on each nontraded good; these shares are not constant as the number of goods in each category will change over time.

⁹ Unless one country is much larger than the other, so that the larger continues production in all industries, including those in which the smaller is specialized. In this situation, relative prices adjust so as to generate Ricardian results.

B. Dynamics of Specialization

The discussion of the dynamics of the model is conducted from the perspective of autarky. First, take relative productivities as given and determine the ranking of industries. This establishes the short-run equilibrium position which will be altered by different relative labor allocations. Then consider the pattern of trade that develops over time from this initial equilibrium position. It is in this discussion that the differences will be revealed in considering the contracting system present in this model, rather than a growing system such as in Krugman's model.

I begin by determining the allocation of labor among industries over time. At a point in time, this model is Ricardian. In autarky, tradable good industries can be ranked by their relative productivities, $A_i(t)/a_i(t)$. The marginal industry (which produces the nontraded good) is required to meet

$$[4] \quad \frac{A_i(t)}{a_i(t)} = \frac{W(t)}{w(t)}$$

where $W(t)$ is the wage rate in the marginal industry at time t . The relative wage rate $W(t)/w(t)$ will result from trade because trade tends to equalize wage rates across industries. This equalization occurs because engaging in trade allows labor to be reallocated according to comparative advantage. The trading equilibrium with production of all commodities involves labor moving between industries until returns to labor become equal in all industries.

When the relative productivity in an industry is just equal to the prevailing relative wage rate, neither country has a comparative advantage in the industry so the

product will be produced domestically and not be traded. On the other hand, if

$\frac{A_i(t)}{a_i(t)} > \frac{W(t)}{w(t)}$, the good is an export for Home and an import for Foreign because

Home has a comparative advantage in the industry (if $\frac{A_i(t)}{a_i(t)} < \frac{W(t)}{w(t)}$, the opposite is

true). Comparative advantage is established by the relative productivity in an industry exceeding the relative wage rate in the marginal industry and thus, the relative wage rate that will prevail in all industries with trade. We define $\sigma(t)$ as the continuous line segment representing industries, ranked in order from highest to lowest relative labor productivity for Home, expressed as a percentage of the total number of industries (n), for any wage-labor force combination. This allows us to establish one of the short-run equilibrium conditions with equation [4]. This equation is shown in figure 3 as downward-sloping because as Home's share of the tradable industries (i.e., Home's share of $\sigma(t)$) increases, the marginal industry has a lower and lower relative wage. This occurs because the relative wage reflects the rankings of the relative productivities. Relative productivities are ranked in order from highest to lowest, so as $\sigma(t)$ increases the marginal industry is of lower and lower rank.

The other short-run equilibrium condition is the balance of payments (trade) equilibrium which is used to identify the marginal industry and corresponding shares of goods produced by Home and by Foreign. Since equation [4] represents the supply side in the short run, we need to derive the demand side to determine short-run

equilibrium.¹⁰ Given that expenditure is equal to income, equilibrium in the market for Home-produced goods requires that Home's labor income ($W(t)\bar{L}(t)$) equals world (Home and Foreign) spending on Home-produced goods. This gives

$$W(t)\bar{L}(t) = \sigma(t)(W(t)\bar{L}(t) + w(t)\bar{l}(t))$$

where $\bar{L}(t)$ is the exogenously fixed size of the labor force. We can rewrite this condition to yield the trade balance equilibrium

$$(1 - \sigma(t))W(t)\bar{L}(t) = \sigma(t)w(t)\bar{l}(t)$$

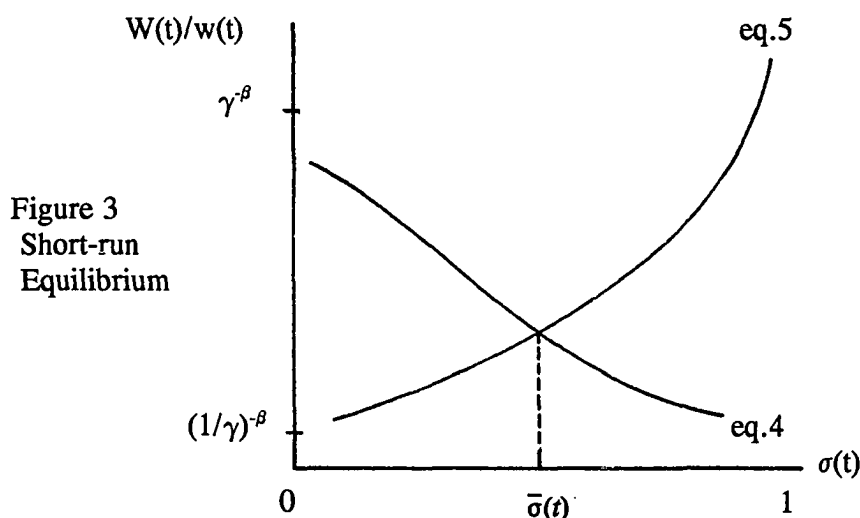
This states that imports are equal in value to exports (with respect to Home, the left-hand side represents imports and the right-hand side represents exports). By rearranging, the trade balance equilibrium yields the condition that determines the equilibrium value of $W(t)/w(t)$ (with equation [4]), which is written as

$$[5] \quad \frac{W(t)}{w(t)} = \frac{\sigma(t)}{1 - \sigma(t)} * \frac{\bar{l}(t)}{\bar{L}(t)}$$

This condition shows that the relative wage is proportional to the amount of production taking place in each country. The reasoning is as follows. If Home's share of world production increases (with stable relative wages), Home's exports will increase and Home's imports will decrease. In order to maintain stability, Home's relative wage must rise. This decreases exports, increases import demand, and restores balance. Equation [5] also yields the relative wage at which Home's demand for labor (goods) is just equal to Home's supply of labor (goods). For all industries

¹⁰ This analysis is derived from Dornbusch, Fischer, and Samuelson (1977).

other than the marginal industry, any imbalance is accounted for by trade. The short-run equilibrium can be demonstrated as in figure 3.



The intersection of equations [4] and [5] yields the short-run equilibrium relative wage rate (and relative productivity) for the nontraded good industry, given the initial allocation of labor. It thereby establishes, prior to trade, the industries in which each of the countries has a comparative advantage. Thus $\bar{\sigma}(t)$ is the equilibrium share of the world's tradable good industries located in Home - that is, the number of tradable good industries in which Home has a comparative advantage relative to the total number of tradable good industries. Home will export the goods of industries with relative productivities above the equilibrium relative wage rate (from 0 to $\bar{\sigma}(t)$); Foreign will export the remainder (from $\bar{\sigma}(t)$ to 1). The values $(1/\gamma)^\beta$ and γ^β are asymptotes for equation [4] derived from the fact that

$$\text{equation [4] is } \frac{W(t)}{w(t)} = \frac{A_{i*}}{a_{i*}} \left(\frac{P_i(t)}{p_i(t)} \right)^{-\beta} \text{ for the nontraded good industry.}$$

Now we can discuss the dynamics of specialization over time. In so doing, we can see how the accumulation of pollution impacts on comparative advantage in the system. As production takes place in each country, the pollution generated serves to decrease labor productivity from its initial level, leading production to decline in the next period, the amount of new pollution produced declines, productivity declines more slowly, etc. This occurs in every industry in which the country initially has a comparative advantage. Because productivity diminishes, the magnitudes of the comparative advantages decline between the two countries over time. The productivity decline causes goods to become nontraded as comparative advantage is eroded away.

The analysis of the dynamics of relative productivity can be demonstrated for a representative industry using a phase diagram (the mechanics are the same for any industry).¹¹ This analysis can be generalized to the effects of trade on comparative advantage for all industries. We set up the phase diagram for a particular industry prior to trade and for expository ease we assume equal-sized industries in both countries. In a phase diagram in which we examine the values of the productivity measures $A_i(t)$ and $a_i(t)$ along the axes, the directions of motion are dictated by the isokines - that is, the reference lines along which the rate of change in the productivity measure over time, $\frac{dA_i(t)}{dt} = \dot{A}_i$ or $\frac{da_i(t)}{dt} = \dot{a}_i$, is equal to zero. The

¹¹ The following discussion of the phase diagram, and derivation of isokines, draws on the presentation and analysis in Beavis and Dobbs (1990). Phase diagrams are a means of illustrating motion in dynamic systems.

isokine analysis demonstrates the directions of movement in productivities over time (in this case, motion is directed towards the isokines). The movement of the isokines from the autarky to the trade position highlights the impact of trade on comparative advantage.

Substituting equation [3] into [2] to solve for the isokines we find that the change in labor productivity over time is a function of the change in pollution over time, given the rate of growth in the pollution function and the level of accumulated output; this yields

$$[6] \quad \frac{dA_i(t)}{dt} = \dot{A}_i = \frac{-\beta A_{i*} dP_i(t)/dt}{\left[\int_{t_0}^t (X_i(t) + \gamma x_i(t)) dt \right]^{\beta+1}}$$

$$\frac{da_i(t)}{dt} = \dot{a}_i = \frac{-\beta a_{i*} dp_i(t)/dt}{\left[\int_{t_0}^t (\gamma X_i(t) + x_i(t)) dt \right]^{\beta+1}}$$

where $\frac{dP_i(t)}{dt}$ is equal to (from [3])

$$[7] \quad \frac{dP_i(t)}{dt} = X_i(t) + \gamma x_i(t)$$

$$\frac{dp_i(t)}{dt} = x_i(t) + \gamma X_i(t)$$

To find $\dot{A}_i = 0$ and $\dot{a}_i = 0$, we substitute [1] into [7] and the result into [6].

Also, notice that from [6] it is sufficient that the numerator, denoted \overline{A}_i or \overline{a}_i , is equal to zero because the denominator is positive, so we have

$$[8] \quad \overline{A}_i = -\beta A_{i*} \frac{dP_i(t)}{dt} = -\beta A_{i*} [A_i(t)L_i(t) + \gamma a_i(t)l_i(t)] = 0$$

$$\overline{a}_i = -\beta a_{i*} \frac{dp_i(t)}{dt} = -\beta a_{i*} [\gamma A_i(t)L_i(t) + a_i(t)l_i(t)] = 0$$

Thus, for \overline{A}_i or \overline{a}_i to be equal to zero, $L_i(t)$ and $l_i(t)$ must be equal to zero since all the other terms are positive. The relevance of [6] and [8] is that the isokines $\dot{A}_i = 0$ and $\dot{a}_i = 0$ can be established.

In order to use the isokines, we must determine their slopes so that we can locate them in $A_i(t)$, $a_i(t)$ space. If trade is taking place, complete specialization means that in any particular industry either $L_i(t) = 0$ or $l_i(t) = 0$. Therefore, the isokines for an industry with trade are coincident with the two axes in figure 4 below. However, in autarky when both countries are producing all goods, we can find the slopes of the isokines as follows. With $a_i(t)$ on the horizontal axis, the slopes of the isokines are defined as

$$[9] \quad \frac{\partial a_i}{\partial A_i} \Big|_{A_i=0} = \frac{-\overline{A}_{i a_i}}{\overline{A}_{i A_i}}$$

$$\frac{\partial a_i}{\partial A_i} \Big|_{a_i=0} = \frac{-\overline{a}_{i a_i}}{\overline{a}_{i A_i}}$$

where $\overline{A}_{i a_i}$ is the partial derivative of \overline{A}_i with respect to a_i . Using [8], we can solve

for [9] and determine that the slopes of both isokines are negative as shown

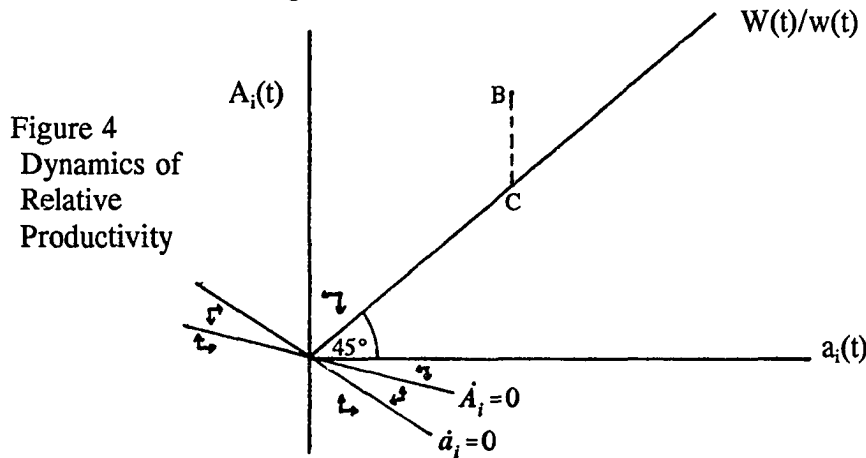
$$[10] \quad \frac{\partial a_i}{\partial A_i} \Big|_{\dot{A}_i=0} = \frac{-(-\beta A_i \gamma L_i(t))}{-\beta A_i L_i(t)} = \frac{-\gamma L_i(t)}{L_i(t)}$$

$$\frac{\partial a_i}{\partial A_i} \Big|_{\dot{a}_i=0} = \frac{-(-\beta a_i L_i(t))}{-\beta a_i \gamma L_i(t)} = \frac{-L_i(t)}{\gamma L_i(t)}.$$

In order to analyze the autarkic dynamics, we need to position these isokines in the phase diagram shown in figure 4 at the origin. We know from the foregoing discussion that over time pollution continues to decrease productivity, and therefore the origin represents a normalized low value of relative productivity. We then use the isokines to derive the directions of motion in the phase diagram. For purposes of discussion we take the particular example mentioned earlier and assume equal-sized countries and equal-sized industries so that $L_i(t) = l_i(t)$; we also assume the prevailing relative wage rate $W(t)/w(t) = 1$. Thus, the equations in [10] reduce to

$$\frac{\partial a_i}{\partial A_i} \Big|_{\dot{A}_i=0} = -\gamma \text{ and } \frac{\partial a_i}{\partial A_i} \Big|_{\dot{a}_i=0} = -\frac{1}{\gamma}, \text{ and we have isokines and directions of motion}$$

located as shown in figure 4.



The ray representing $W(t)/w(t)$ is the reference line for determining initial comparative advantage. The phase diagram is analyzed as follows. If we were to

start from a point such as **B**, initially $\frac{A_i(t)}{a_i(t)} > \frac{W(t)}{w(t)}$ and Home has a comparative

advantage in this industry, so Home is producing and exporting this good. Therefore,

$l_i(t) = 0$ and the isokines are coincident with the axes. Until the point at which we

reach the $W(t)/w(t)$ reference line, where $\frac{A_i(t)}{a_i(t)} = \frac{W(t)}{w(t)}$ and both countries begin

producing the good, Home is the sole producer and exporter. Engaging in production

increases Home's pollution; thus, $A_i(t)/a_i(t)$ falls because in moving from **B**, $a_i(t)$

remains constant but $A_i(t)$ is being diminished by the pollution function $P_i(t)^8$. As

$A_i(t)/a_i(t)$ falls, comparative advantage deteriorates and Home's production and

exports decrease. We have the result that specializing in production and export

according to comparative advantage diminishes productivity, and therefore

comparative advantage, until we reach point **C** and the good is no longer traded.

Given the location of the isokines with trade, the movement from **B** to **C** will be

strictly vertical.

The question next arises concerning what happens once we reach point **C** when

both countries begin producing in this industry. At this point, the relevant isokines

are those shown in figure 4 at the origin. If both countries are producing this good,

pollution in this industry is increasing in both countries, and therefore productivity is

diminishing in this industry in both countries. But, do productivities diminish at the

same rate? If so, this would maintain a constant relative productivity, and we would

move from **C** to the origin along the ray $W(t)/w(t)$. If productivities do not diminish at the same rate, we could move in a stair-step fashion from **C** down to the origin, or switch back and forth across the $W(t)/w(t)$ ray down to the origin, or - as it turns out - move from **C** to the origin in almost any imaginable manner.

The reason for the numerous possibilities is that relative productivity $A_i(t)/a_i(t)$ is a function of A_{i*} , a_{i*} , $P_i(t)$, and $p_i(t)$. The manner in which relative productivities diminish depends on the relationships among the values of these variables, and the rate at which $P_i(t)$ and $p_i(t)$ increase. Suppose, for example, we assign the arbitrary values $A_{i*} = 5$ and $a_{i*} = 3$, and assume that $P_i(t) > p_i(t)$. (This could apply at a point like **B** and thereby lead to point **C**). Then relative productivity

$$\frac{A_i(t)}{a_i(t)} = \frac{\frac{5}{P_i(t)^\beta}}{\frac{3}{p_i(t)^\beta}} = \frac{5}{3} \left(\frac{p_i(t)}{P_i(t)} \right)^\beta, \text{ and the rate at which relative productivity changes over}$$

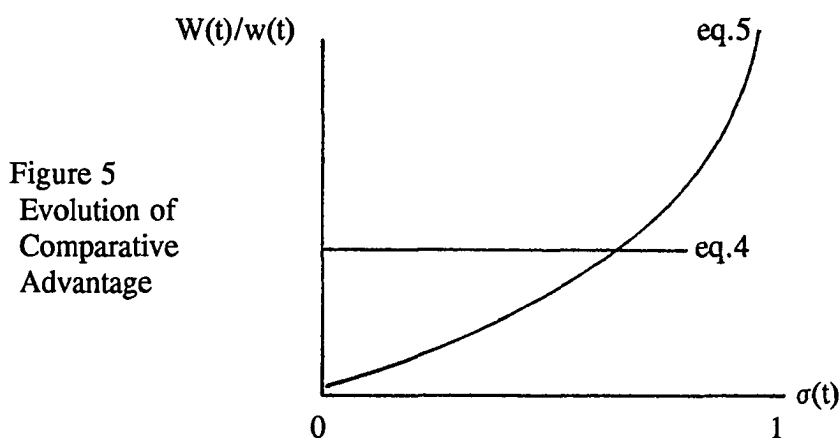
time could be greater than, less than, or equal to one (depending on the values of $P_i(t)$ and $p_i(t)$ relative to 5 and 3, respectively).

Fortunately, for our purposes, the large number of possibilities does not create a problem because the end result is always the same. When production takes place, pollution accumulates, and productivity diminishes. This happens in every industry for both countries and productivity diminishes until it approaches zero. As productivity diminishes, comparative advantage is destroyed, and goods become

nontraded. We know that this is always the result because of the directions of motion shown in the phase diagram.

The numerous possible paths will be useful in further research when the model is made more realistic and expanded to include mitigating factors such as pollution abatement activity. In such a case, it becomes more critical to understand the precise relationships among the values of the variables.

In the meantime, as shown in figure 5 below, the result is that the graph of equation [4] will flatten as the differences between relative productivities become smaller (and vanish) and all goods become nontraded. Recall that $\sigma(t)$ is interpreted as the set of industries and ranges from 0 to 1.



Thus, rather than a single nontraded good, all goods now form a range of nontraded goods, being produced in both countries, which has grown over time. As all goods are nontraded, the relative productivity is the same in all industries, and no country has a comparative advantage in any industry. Given the range of possibilities, we cannot say for certain which industries will first become nontraded, or which will

switch between countries (if at all), but we can establish that the ultimate result will be as depicted in figure 5.

The impact of accumulating pollution is to destroy comparative advantage by diminishing labor productivity in every industry in which a country is specialized. This result holds whether we adjust the model for the complete specialization of the Ricardian framework, or allow the possibility of incomplete specialization and internationally transmitted pollutants.

Differential impacts on countries are possible; any action that increases the amount of output produced will increase the amount of pollution generated and diminish productivity faster. Increased output can occur if, for example, a country begins with a higher relative labor allocation or a higher initial productivity level in an industry.

At the same time as comparative advantage is being destroyed, due to the fact that productivity declines, real wages must fall in each country (even if the prevailing relative wage remains constant) and output must fall in every industry in which a country is specialized. Because of the original specification of the model, consumption thus also declines. Therefore, the final autarky position is likely to be worse than the original autarky since output, consumption, and real wages are all lower. As noted earlier, trade and specialization according to comparative advantage enhance the final result. The two countries are eventually simply meeting their own smaller needs, and trade ceases. Goods are produced at minimal levels in each country with worldwide pollution at a high level and labor minimally productive.

Since we assume laborers do not die, and given the specification of labor productivity, the final autarky position is reached before pollution completely destroys labor productivity (and the natural environment). That is, productivity approaches, but does not reach, zero, and some minimal production can continue indefinitely even if each individual laborer's productivity is nearly zero.

Thus, in this model comparative advantage is derived from relative pollution levels and the associated relative labor productivities, and therefore changes over time. Comparative advantage arising from an underlying national characteristic, namely technology, serves only as the initial trigger for the system. The generation of pollution over time causes the system to virtually grind to a halt if there are no mitigating forces. While this result is intuitive, it is also important because the result differs from that of the static comparative advantage models with pollution. As discussed in the second essay, the static models show that the environment-abundant country will specialize on the environment-intensive good; while this may solve the pollution problem in the short run, in the long run (over time) this type of specialization will not reduce or eliminate the destruction of the environment. The dynamic model developed here essentially confirms our intuition concerning declining environmental quality in demonstrating the implications of pollution generated through production.

C. Conclusion

The model presented in this essay has demonstrated the fundamentals of the relationship between pollution and trade over time. The only complicating feature introduced in this preliminary model was the possibility that pollution may be transmitted internationally. It should again be emphasized that the present model is a tentative first step in the development of a model of the relationship between trade and environmental degradation. However, even this tentative simple model has presented novel results.

The finding that comparative advantage is diminished if pollution occurs in the production process (with no abatement) and countries open to trade is a new result. The literature on environment and trade, and on natural resources and trade, such as discussed in the second essay, generally concentrates on the circumstances under which countries maintain comparative advantage. In such discussions, the focus is on the recommended shift out of environment-intensive goods for a country depleting its environment, or the recommended time path of the use of a depletable resource. The models produce results in which a country is able to have a comparative advantage in some industry and continue to engage in trade, regardless of the fact that the environment is damaged or depleted, because the country can shift to an activity or resource that is less deleterious. This result is only feasible in the models of pollution because the trade models upon which they are based are static.

In contrast, the model presented in this essay produces a new result that pollution destroys comparative advantage because all industries pollute and eventually

lead to the same autarkic result, whether or not industries are equally pollution-intensive. Since pollution acts directly on the countries' only source of comparative advantage - a relative productivity differential - there is no way to escape the inevitable conclusion if pollution cannot be dissipated or abated. This finding is a result of the use of a dynamic model which recognizes that pollution is a continual problem and by-product of economic activity.

This finding is also a result of asking a different question about pollution and trade. The existing literature asks how a country can maintain a basis by which it can continue to engage in trade in the face of increasing pressures on its environment. The model in this essay simply asks what happens if in the course of engaging in trade, pollution is being generated in the production process over time. This model is willing to accept destruction as a result because it recognizes that pollution is an unavoidable factor with negative impacts. In return, the model exposes itself to the necessity of more realistic modifications - such as the introduction of pollution abatement activities - that will potentially moderate the dire result.

On another point, the existing literature suggests that engaging in pollution control activities will tend to decrease a country's competitiveness. Relatively strict environmental regulations are theorized to put a country at a disadvantage relative to countries with less strict regulations. This is the result of Pethig (1976) and McGuire (1982), among other models discussed in the second essay. The model developed in this essay, by contrast, finds that *pollution generation* causes a country to lose its comparative advantage, suggesting that the addition of pollution control (abatement) to

this model would mitigate such a result. Considering trade in a dynamic setting seems to produce contradictory conclusions to the conventional wisdom.

With respect to the final autarky result of this model, it may appear that such a dire conclusion is too strong. However, there are several mitigating elements that have been left out of the analysis at this stage in the model's progress. First, as discussed above, the model allows no possibility for pollution abatement activities.¹² Engaging in abatement would reduce or stop the productivity decline in the industries targeted for abatement, by reducing either the amount of pollution produced or the detrimental impact of pollution on labor productivity, and trade could likely be maintained in these industries. Second, we have assumed that all industries are equally pollution intensive. Differences in pollution intensity could be specified as a multiplicative factor in equation [3] (similar to γ). Trade would be maintained in those industries that did not pollute (i.e., "green" industries), and trade would decline more slowly in the less pollution-intensive industries. A combination of pollution abatement and differences in pollution intensity would likely produce a result in which production and trade could be maintained in a larger number of industries.

Finally, another mitigating factor might be the introduction of a "health care system"; that is, the introduction of a factor which improved worker's health, and productivity, in the face of increasing pollution. Introducing any type of mitigating factor would significantly complicate this simple model. We have noted, however,

¹² It likewise does not allow for pollution to dissipate, which is a form of natural abatement, or for the system to achieve sustainability.

the likely impacts which suggest themselves based on the fundamentals of the relationships.

Additionally, it should be possible to extend the implications of this model to the case of two countries with different "environmental endowments", that is, where one country has not yet exceeded the environmental assimilative capacity. In essence, this involves the assumption that (for example) Foreign's labor productivity remains constant at a_i , and $p_i(t)$ does not figure into the model. The expected result is that over time increasing pollution and decreasing labor productivity in Home should create a comparative advantage in new industries for Foreign. Foreign cannot export all goods because of the balanced trade requirement, but it would tend to gain a large proportion of the industries. Over time, however, increased production in Foreign would likely cause it to finally exceed the environmental assimilative capacity, and generate the final autarky result unless mitigating factors were introduced.

In sum, it appears that this framework provides a fruitful structure for a theoretical model combining dynamic comparative advantage and the problem of pollution over time. It suggests that the static comparative advantage patterns of Heckscher-Ohlin models of trade which consider the environment as a factor of production could not be maintained over time. This model further suggests that the neoclassical conclusion that opening to free trade is always beneficial is reversed if we allow for polluting industries in a dynamic setting. This is an intuitively appealing demonstration of the impact of ignoring externalities, and raises questions about the policy proscriptions of laissez-faire. In addition, it offers a possible explanation for

why empirical models incorporating environmental degradation have failed to support the theoretical results of Heckscher-Ohlin (such as Leonard (1988) and Tobey (1990) which were discussed in the second essay), in that attempts to analyze environmental impacts using a model only valid for a snapshot in time may be frustrated by the dominance of the long-run effects of pollution. Unfortunately, the challenge faced in conducting empirical testing of this model in its present form is quite formidable.

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APPENDIX A
DATA APPENDIX FOR SECTION 2

This appendix supplements the information provided on data in the second essay. It contains the industry categories and data sources used, as well as a discussion of the environmental variable. Based on the concordances for output and trade data from Maskus (1991), there are 25 industrial categories in the manufacturing sector used in this study. These are listed in Table A-1 with the Input-Output Table, SITC, and ISIC industry numbers to which they correspond. Omitted from the table (but available in concordances) are the weights used for SITC industries.

Table A-1
Manufacturing Sector Industrial Categories

	IO	SITC	ISIC
Food & Kindred Prod.	14	01-09,11,21,22,29,41-43,59	311/2/3
Tobacco Manufactures	15	12	314
Textiles	16,17,19	26,65,84	321
Apparel	18	84	322
Wood Products	20,21	24,63	331
Furniture & Fixtures	22,23	82	332
Paper & Products	24,25	25,59,64	341
Printing & Publishing	26	64,89	342
Indus. Chems. & Paints	27,30	23,26,43,51-53,56,58,59	351
Plastics & Synth. Materials	28	58,82,89	356
Other Chemical Prod.	29	53-55,57,59	352
Petrol. Refg. & Rel. Indus.	31	33,34	353
Rubber & Misc. Plast. Prod.	32	23,62	355
Leather Tanning & Finishing	33	61,83	323
Footwear & Other Leather Prod.	34	61,85	324
Glass & Glass Prod.	35	66,81	362
Stone & Clay Prod.	36	27,66,81	361/9
Primary Iron & Steel Mfg.	37	67,69	371
Prim. Nonferrous Metals Mfg.	38	68,69	372
Metal Prod.	39-42	67-69,71,73,74,81	381
Machinery, n.e.c.	43-50	69,71-75,77	382
Electrical Machinery	51-58	76,77	383
Transport Equipment	59-61	71,74,78,79,89	384
Professional Goods	62-63	54,59,74,86	385
Miscellaneous Mfg.	64	69,83,89	390

Data are collected for trade flows, factor endowments, and factor intensities - the three variables in the Heckscher-Ohlin-Vanek equations for which independent observations are required in a complete test. For the "typical" factors in the Heckscher-Ohlin-Vanek equations, Maskus (1991) is an especially detailed source of data information. The sources of 1975 or 1977 data¹ on factors used here are: International Labour Office (1977-79) *Year Book of Labour Statistics* (for the labor endowments); Bureau of Labor Statistics (1980) *Occupational Employment in Manufacturing Industries* (labor-output ratios) and (1979) *Capital Stock Estimates for Input-Output Industries* (capital-output ratios - Musgrave (1981) is used to extrapolate these); and FAO (1978) *Production Yearbook* (land endowments). Factor intensities for types of land are calculated as proportional to the output of the corresponding input-output sector. Trade data are obtained from UN (1978-79) *Commodity Trade Statistics*. Exchange rates and deflators are found in IMF (1979) *International Financial Statistics* (also the source of capital endowments) and *Economic Report of the President 1991*, as well as Ward (1985) and Summers and Heston (1988).

These data are matched up with two other types of data that influence the time period and countries chosen for this study. The countries examined are: Canada, France, West Germany, Italy, Japan, the United Kingdom, and the United States. These are some of the countries for which OECD (1991) *Environmental Data Compendium* has information on air pollutant emissions endowments. Air pollution was chosen in part for reasons of data availability. For pollution-output ratios by

¹ The reason for the use of these years is discussed below.

industry, U.S. EPA (1978-79) *National Emissions Report* lists emissions of air pollutants by industry (for both total emissions and emissions of specific pollutants); these were matched up with the corresponding industries included in the final Input-Output matrix. Since the single A matrix is assumed to apply to all countries, these emissions intensities are assumed to do so as well since they are derived from the identical technologies assumption. Emissions data are only available for certain years, so other data must be matched to these years as closely as possible.²

Thus, in the empirical analysis used here, the environment endowment (E_k) and factor intensity are proxied for by using air pollution emissions. Since the generation of emissions can be thought of as a measure of the use of the environment, this interpretation takes as true the idea that factor supplies are equivalent to factors used in the Heckscher-Ohlin-Vanek context. Air pollution is used as it is the most serious problem facing virtually all of the seven countries; only one type of pollution could be used as it is conceptually difficult to aggregate different types of pollution (air, water, land, etc.). Only stationary source emissions are used because these are the primary emissions associated with industrial production (where possible, only industry sources are included); the emissions include the major air pollutants: sulfur oxides, nitrogen oxides, hydrocarbons, carbon monoxide, and particulates. The use of emissions captures some of the influence of environmental assimilative capacity. The impact of regulations is captured in part in the emissions by industry - but this masks the

² Unfortunately, not all the data are available for exactly the same year, and some extrapolations must be used. I use 1975 emissions endowments as the closest to the 1977 Input-Output Table; 1975 emissions intensities are extrapolated to 1977 using pollution abatement costs from U.S. Bureau of the Census (1977-79).

variation by country. It is assumed here that any differences that exist between countries are small in magnitude.³

The introduction of the environment into this model is accomplished by using a quantitative variable which attempts to address both the ideas of environmental assimilative capacity and the state of existing regulations. It is not a perfect solution to the shortcomings of other models - especially as it is limited to one aspect of the environment (air) - but it is hoped that the results will reveal whether it is a step in the right direction.

The year chosen largely depends on the availability of the bulk of the information used to create the A matrix. One of the latest years for which the U.S. Input-Output Tables are available using the most reliable data is 1977 (*Survey of Current Business* May 1984).⁴ Thus, the data for this study will be for years as close as possible to 1977.

³ Given the lack of information concerning the magnitude of differences in regulations discussed earlier, this assumption may be questionable. As has been noted, such an error may be indicated by poor performance of the environment variable.

⁴ Updates are available, apparently based on adjusting the 1977 tables rather than reexamining industrial structure, for more recent years; also, there are 1982 tables available.

APPENDIX B

RESULTS WITHOUT ENVIRONMENT FOR SECTION 2

The results of the nonparametric tests and regression analysis discussed here concern the data set with the environment variable (E) removed. This discussion highlights the contribution of the environment variable to the analyses, and supplements the discussion in the second essay.

The details on the nonparametric tests are provided in the main text. For the results of the sign test for each factor across the seven countries in the study, refer to Table 11 in the text. In this table we see that without the environment (E), high skill labor (L^H) is the factor with the smallest proportion of sign matches (.428); this value is the same as that for E. The results of the sign test for each country across the five factors are provided in Table B-1. Compared to the results across all six factors shown in Table 12 in the text, we see that the environment was sometimes a factor for which there was a sign match, and sometimes not. Thus, the sign test results improved for some countries but not for others when the environment was excluded (Table B-1). Overall, omitting the environment does not alter the lack of support for Heckscher-Ohlin-Vanek found on the basis of the sign test in the text. In addition, when Fisher's exact test is conducted on the sign test results reported in Table B-1, the finding is that in no case can the null hypothesis of independence be rejected (the same result as in the text).

The results of the "rank" test for each of the factors across the seven countries in the study are shown in Table 11 in the main text. We see that by omitting the environment (E), the overall level of support for Heckscher-Ohlin-Vanek provided

Table B-1. Ranking of Countries Across Factors - Excluding E¹

<u>Country</u> ^{2,3}		<u>K</u>	<u>N^A</u>	<u>N^F</u>	<u>L^H</u>	<u>L^L</u>	<u>W</u> ⁴	<u>Sign</u> ⁵
Canada	F.C.	3	2	1	4	5		
	F.E.	3	2	1	4	5	1.0000 ^a	.8
France	F.C.	3	1	2	4	5		
	F.E.	1	4	5	2	3	.2500	.6
W.Ger-1	F.C.	2	4	5	1	3		
	F.E.	1	4	5	3	2	.8500 ^c	
W.Ger-2	F.C.	3	4	5	1	2		
	F.E.	1	4	5	3	2	.8000 ^d	.6
Italy-1	F.C.	3	5	1	4	2		
	F.E.	2	4	5	3	1	.5000	
Italy-2	F.C.	4	5	1	3	2		
	F.E.	2	4	5	3	1	.4500	
Italy-3	F.C.	3	5	1	4	2		
	F.E.	3	4	5	2	1	.4500	.4
Japan-1	F.C.	3	5	4	1	2		
	F.E.	2	5	4	3	1	.8500 ^c	
Japan-2	F.C.	3	5	4	1	2		
	F.E.	1	5	4	3	2	.8000 ^d	.8
UK-1	F.C.	3	4	5	2	1		
	F.E.	3	4	5	2	1	1.0000 ^a	
UK-2	F.C.	2	4	5	3	1		
	F.E.	3	4	5	2	1	.9500 ^b	.6
US	F.C.	3	1	5	2	4		
	F.E.	4	1	3	2	5	.8500 ^c	.8

¹ See footnote 1 to Table 12.

² F.C. - factor content measure ranking; F.E. - factor endowment measure ranking. Also see footnote 2 to Table 10.

³ For some countries the way in which K was measured changed the ranking, thus the differing results are presented. See footnote 3 to Table 12: but UK-1 (K₁, K₃, or K₄), UK-2 (K₂).

⁴ Value of Kendall's coefficient of concordance; $0 \leq W \leq 1$ ($r = 2$, $c = 5$). **a** indicates statistically significant at .01 level. **b** indicates statistically significant at .05 level. **c** indicates statistically significant at .10 level. **d** indicates statistically significant at .20 level.

⁵ Proportion of sign matches.

through this version of the "rank" test is increased. The factor with the lowest degree of concordance (lowest W value) now is capital - .5714 for K_3 , K_4 and .5893 for K_1 , K_2 ; these values are larger than that for E .

The results of the "rank" test for rankings of each country across five factors (excluding E) and the respective W values are presented in Table B-1. Except for France and Italy, the rankings for each country demonstrate a higher degree of concordance than Table 12 in the text; now both Canada and the United Kingdom have W values equal to unity. All W values (except for France and Italy) are statistically significant at least at the .20 level. The results of this version of the "rank" test suggest even more support for the Heckscher-Ohlin-Vanek theorem than in Table 12, and seem to indicate that the environment factor distorts the concordance of the rankings in the test. This suggests either that the proxy chosen is weak and does not adequately reflect the impact of the environment as a factor or that the environment is not a factor of production in the same manner as capital, labor, and land. The explanation for the poor performance for France and Italy is likely related to the quality of the data available for the various countries.

For the results of the "strong" test, refer to Table 13 in the text. We see that omitting the environment (E) does not alter these results because the percentage deviations generated by this factor were in the middle of the range of deviations generated by all factors; capital had the smallest values and land had the largest.

Thus, removing the environment variable (E) from the data set strengthened the results of the "rank" test, but had no significant impact on the sign or "strong" tests.

Because of the improvement in the "rank" test, the nonparametric tests now suggest somewhat stronger support for the Heckscher-Ohlin-Vanek model. This finding suggests that the environment was a weak variable in the nonparametric tests, and tended to obscure the true relationships.

The regression results for the data set with the environment variable (**E**) removed are presented in Tables B-2 and B-3. The discussion of the different versions (**[A]** and **[B]**) of the Heckscher-Ohlin-Vanek equations used is provided in the main text. Given that only a slight difference can be attributed to the use of the different measures of capital, results are only reported for K_1 (corresponding to the equations identified as (1) in Tables 14 and 15 in the text). Table B-2 shows that the estimated coefficients β_1 and β_2 in equation **[A]** are in both cases significant at the .01 level and have the signs predicted by the Heckscher-Ohlin-Vanek model. The constant term is not significant, and does not significantly alter the estimated values of β_1 and β_2 when it appears in the equation. The F statistics are significant at the .01 level. These results suggest strong support for Heckscher-Ohlin-Vanek, confirming the results of the "rank" test discussed above. Comparing these results to the results in Table 14 in the text, it appears that the environment variable is highly influential in the regressions.

The results in Table B-3 support the relationship just discussed for equation **[A]**. In both versions of equation **[B]**, the estimated coefficient γ_1 is significant at the .01 level and has the correct (positive) sign. The constant term is not significant, and its presence or absence does not alter the estimated value of γ_1 . The F statistics are

Table B-2. Regression Results for Equation [A] (Excluding E)

$$[A] \quad F_{xk}^i = \beta_0 + \beta_1 F_k^i + \beta_2 [(C_k/C_w) F_w^i] + \epsilon_A$$

(t statistics in parentheses)

	β_0	β_1	β_2	F-Statistic	R ²
(1)	-4959.8 (-.465)	.0174 (7.080)***	-.0177 (-7.932)***	33.922***	.6795
(1)		.0171 (7.220)***	-.0176 (-8.018)***	34.962***	.6794

Number of Observations: 35

Significance Level: *** = .01

Table B-3. Regression Results for Equation [B] (Excluding E)

$$[B] \quad F_{xk}^i = \gamma_0 + \gamma_1 (F_k^i - (C_k/C_w) F_w^i) + \epsilon_B$$

(t statistics in parentheses)

	γ_0	γ_1	F-Statistic	R ²
(1)	-7597.3 (-.805)	.0180 (8.306)***	68.989***	.6764
(1)		.0180 (8.349)***	69.709***	.6722

Number of Observations: 35

Significance Level: *** = .01

significant at the .01 level. Again, the results of the "rank" test are confirmed, and the results in Table 15 in the text are completely reversed. It appears in this case that the environment variable is also the source of substantial influence.

A topic for future research is the investigation of the influence that is associated with the observations on the environment variable (E) in the data set. As discussed in Kmenta (1986: 424-426), if one is satisfied that the observations that appear to be influential are not in error, these observations should not be excluded from the data set because they are a valuable source of information. Instead, one needs to determine if the observations are influential by investigating the presence of "leverage points" and also by calculating measures of influence. Two possible measures (Kmenta 1986: 425) evaluate the degree of influence an observation has by looking at the difference between estimated regression coefficients (in one case) or predicted values of the dependent variable (in the other case) with and without the influential observation(s). Influential observations have a disproportionate effect on the estimates of the regression coefficients and the predicted value of the dependent variable, and therefore need the particular attention of researchers.

Tests of the restriction $\beta_1 = -\beta_2$ were performed using *t* tests on the equations in Table B-2. In the *t* tests, the null hypothesis that $\beta_1 = -\beta_2$ could not be rejected at the .01 level.⁵ Thus, the proper form for these equations is that specified by the Heckscher-Ohlin-Vanek equations. In particular, the imposition of the restriction

⁵ This result is affected by the presence of multicollinearity between the variables in equation [A]; however, the presence of multicollinearity also requires the use of a single variable as in equation [B].

(equation [B] in Table B-3) is correct. These results further suggest that the environment variable was severely influencing the regression results obtained and discussed in the text.

Given that the functional form of the equations and support for Heckscher-Ohlin-Vanek were borne out by these results, further tests of dummy variables such as those discussed in the text (Tables 16-18) were not conducted. Overall, it appears that the results of the "rank" test and the regressions indicate that without the environment, support is provided for Heckscher-Ohlin-Vanek. This result differs drastically from that found in the text, so caution must be used in interpreting either the text or this appendix as the final word on Heckscher-Ohlin-Vanek. It seems likely that in addition to investigating influential observations, these results should be examined again on a more expanded data set for 1977 so that we can determine if it is the choice of the group of countries that has been the deciding factor in this change in results.